AFIT/GSO/ENS/92D-13

LOCATING AN IMAGING RADAR IN CANADA FOR IDENTIFYING SPACEBORNE OBJECTS

THESIS

William George Schick
Captain, CAF

AFIT/GSO/ENS/92D-13

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Thesis Approval

STUDENT: Captain William G. Schick *CLASS:* GSO-92D

THESIS TITLE: Locating An Imaging Radar In Canada For Identifying Spaceborne Objects

DEFENSE DATE: November 25, 1992

COMMITTEE:	*NAME/DEPARTMENT*	*SIGNATURE*
Advisor	Yupo Chan, PhD PE Professor of Operations Research	Yupo Chan
Reader/ENS	John J. Borsi, Major, USAF Instructor, Operations Research	John Borsi

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THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science (Space Operations)

William George Schick, B.Eng. (Chemical)

Captain, CAF

December, 1992

Acknowledgements

I would like to acknowledge my thesis advisor, Dr. Yupo Chan, and my reader, Major John Borsi. Without their prompting and reminders of the ever ominous deadlines, this thesis would never have come to fruition.

I would also like to thank the AFIT instructors who helped with the difficult astrophysics calculations: Lieutenant Colonel T.S. Kelso for his Pass Scheduler program and the NORAD two-line element sets and satellite catalogue which provided the necessary data to continue with this thesis; and Dr. William Wiesel for his instruction and help in developing a satellite coordinate frame and understanding the mechanics of satellite orbits.

Finally, I would like to extend my love to my wife and children, who have done without a husband and father, or so it seems, for the last eighteen months while I have been absorbed in my studies and thesis.

William George Schick

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Abstract

This research presents a study of the maximal coverage p-median facility location problem as applied to the location of an imaging radar in Canada for imaging spaceborne objects. The classical mathematical formulation of the maximal coverage p-median problem is converted into network-flow with side constraint formulations that are developed using a scaled down version of the imaging radar location problem.

Two types of network-flow with side constraint formulations are developed: a network using side constraints that simulates the gains in a generalized network; and a network resembling a multi-commodity flow problem that uses side constraints to force flow along identical arcs. These small formulations are expanded to encompass a case study using 12 candidate radar sites, and 48 satellites divided into three states. SAS/OR PROC NETFLOW was used to solve the network-flow with side constraint formulations.

The case study shows the potential for both formulations, although the simulated gains formulation encountered singular matrix computational difficulties as a result of the very organized nature of its side constraint matrix. The multi-commodity flow formulation, when combined with equi-distribution of flow constraints, provided solutions for various values of p, the number of facilities to be selected.

LOCATING AN IMAGING RADAR IN CANADA FOR IDENTIFYING SPACEBORNE OBJECTS

I. Introduction

1.1 Background

The military mission of space surveillance is to detect, track, identify, and catalogue all man-made objects in space (28). This is primarily done with optical cameras and sensors located around the globe that provide information on observations to the Space Surveillance Center (SSC) located in the Cheyenne Mountain Complex in Colorado Springs. The SSC occasionally obtains observational data from non-optical sources such as the Haystack Imaging Radar at MIT, and the target tracking imaging radar at Kwajalein Atoll. Both of these imaging radars are effective for identifying objects in space, but are only available to SSC on a limited basis.

Canada has had an active role in the space surveillance mission to date and desires to continue with that mission. To date that involvement has been with NORAD and with optical cameras for tracking. The Canadian National Defence Headquarters (NDHQ) through the Directorate of Air Requirements (DAR) has requested that a study be done on finding the optimal location in Canada for an imaging radar similar to that at Millstone (Haystack radar). The principle behind such a radar is that it can be used to radar image a satellite's characteristics, and together with orbital elements of that satellite, an attempt can be made to determine the satellite's mission and capabilities.

1.2 Research Problem

The objective of this research was to investigate the application of facility location methodology to the problem of locating an imaging radar in Canada for the identification of spaceborne objects. This class of problem is referred to as a facility location problem. To solve this problem, the factors affecting an imaging radar's resolution must be identified, and candidate locations evaluated. Conditions at these sites must be determined and a best site chosen on the basis of these factors and other conditions identified by NDHQ/DAR. A suitable optimization method or methods must be used to determine the "best" solution. This was accomplished by solving the following sub-problems:

- Establishing a list of potential site locations.
- Determining the field of view of an imaging radar for observing spaceborne objects at each of the potential site locations.
- Determining the environmental factors affecting an imaging radar's capabilities.
- Comparing the orbits of the desired spaceborne objects (satellites) with the capabilities of an imaging radar.
- Formulating a facility location model given the determined restrictions and available sites.

A literature search was performed to determine possible methods and is presented in Chapter 2.

1.3 Scope

NDHQ/DAR had requested that this research be for a single site location, but that the model be flexible enough to choose multiple sites should the requirements change. The research should consider existing military sites due to current government reductions in military spending, but does not necessarily have to be limited to solely military sites. NDHQ/DAR stated that additional restrictions may be imposed, but none were put forward during the time frame of this thesis.

1.4 Assumptions and Limitations

The imaging radar is designed to obtain radar images of satellites or space objects that the user is interested in. In other words, the user does not know the capabilities or purpose of that satellite and wishes to find out. Most of this class of satellite would be of the reconnaissance or intelligence gathering type and information on these satellites is classified and unavailable to this researcher. However, the satellites would have to pass over North America to be useful and a group of orbits was chosen that would fit this mold. A user of the imaging radar would have more complete information on the type of orbit and frequency of observations desired and would be able to implement them in the model constraints. It is also assumed that the satellite is always pointing towards its NADIR or some other constant direction. Any additional rotation would only enhance the imaging radar's imaging process and is not taken into account (worst case assumed).

II. Literature Review

2.1 Facility Location

Not much research has been performed on solely military facility location problems, but analogies can be made between military facility location and the current research on facility location models. The literature of facility location models generally concerns itself with problems of locating one or more new facilities in relation to a set of existing facilities, usually with regards to minimizing transportation costs or maximizing profits (17:1129). The usual assumption made is that some cost component exists between each new facility and each of the existing facilities and that this cost can be modelled with a set of numerical equations.

The Weber problem formulated by the German economist, Alfred Weber, allowed each distance to be multiplied by a given weight and was stated as:

$$\text{Minimize} \sum_{i=1}^{3} w_i l_2(x - a_i, y - b_i) \tag{2.1}$$

where:

for $i = 1, 2, 3$, w_i is the positive weight associated with existing facility i,

(a_i, b_i) is the location of existing facility i,

$l_2(\cdot, \cdot)$ is the Euclidean norm, and

(x, y) is the location of the new facility to be determined.

The existing facilities are assumed to be distinct and non-collinear. Normally an iterative procedure can be used to solve the problem if there is an absence of constraints on the new facility location. A geometric solution to this problem was also demonstrated in this article(17:1130), but it is unlikely that this method would be practical for the imaging radar location problem.

One of the most basic location models is the "simple plant location problem" also known as the uncapacitated facility location problem. The problem is to establish a number of facilities with

enough capacity to meet all demands. The equations are solved to obtain the lowest cost alternative considering both facility costs and transportation costs (10:281). The constraints ensure that all locations are serviced by at least one facility, and that the selected service facilities are open. The system of equations for this model is as follows:

$$Z = \text{Min} \sum_i \sum_j c_{ij} x_{ij} + \sum_j f_j y_j \tag{2.2}$$

subject to:

$$\sum_j x_{ij} = 1 \ \ \forall \ i \tag{2.3}$$

$$\sum_i d_i x_{ij} \leq s_j y_j \ \ \forall \ j \tag{2.4}$$

$$0 \leq x_{ij} \leq 1, \ 0 \leq y_i \leq 1, \ \ \forall \ i \text{ and } j \tag{2.5}$$

$$y_j \text{ integer for all } j \tag{2.6}$$

In this formulation, i represents the clients and j the sites where facilities can be located (both assumed to be finite), c_{ij} is the transportation cost incurred if all of client i's demand is met from facility j, and f_j is the fixed cost of operating facility j. The demand of the client i is represented by $d_i > 0$, and the capacity of facility j (if it is open) is $s_j > 0$. The decisions to be made are represented by the variables y_j (1 if facility j is open, 0 otherwise), and x_{ij}, which is the fraction of the demand of client i met from facility j.

This problem is similar to the "p-median" problem which seeks to place p facilities, instead of one, among the demands (14:450). It seeks to minimize the average distance or time between facility and servicing locations. The formulation of the problem is similar to the one above and ensures that each demand point is serviced by the nearest facility. Both of these problems can be solved using standard linear and integer programming techniques, which although inefficient, do work when the problem is small enough, or the computer powerful enough.

The two facility location models mentioned previously are deterministic in nature because the data for the problem (distances and demands) are assumed to be constant and known quantities. Whenever any or all of these quantities are random variables, such as the distance or track of the next unknown satellite passing nearby, the problem becomes probabilistic in nature. Mirchandani and Odoni (22:86) propose the following formulation to deal with the p-median problem with k states:

$$\text{Minimize} \sum_{k=1}^{K} \sum_{i \epsilon I} \sum_{j \epsilon I} Q_k f_{ik} d_{ijk} x_{ijk} \tag{2.7}$$

subject to:

$$\sum_{j \epsilon I} x_{ijk} \geq 1 \quad \forall \ i \epsilon I \text{ and } k = 1, \ldots, k \tag{2.8}$$

$$x_{ijk} \leq x_{jj}, \quad \forall \ i, j \epsilon I;\ i \neq j; \text{ and } k = 1, \ldots, k \tag{2.9}$$

$$\sum_{j \epsilon I} x_{jj} = p \tag{2.10}$$

The above formulation seeks to minimize the weighted sum of the travel distance over all possible states. The probability associated with each state, Q_k, provides the weight. The variable x_{ijk} takes on the value of one when demand point i is assigned to facility j in state k. Therefore, this type of formulation allows for facility assignments (x_{jj} equals 1 or 0) to vary from state to state based on the value of d_{ijk} which could represent varying travel times based on time of day.

The previous formulations have been based on minimizing distances and costs. In some cases one has to maximize a distance such as locating the radar away from interference sources or in locating undesirable facilities (obnoxious facilities) such as garbage dumps, a chemical plant or a nuclear reactor (12:275). Another term for this type of problem is "maximin" which implies that some of our functions are being minimized (travel cost is still a factor) while others are being maximized (but no one wants to live close to the dump). This type of problem formulation is much

more difficult and objective weightings have to be given to various portions of the equations. These relate to the degree of desirableness or undesirableness of the various distances and costs.

2.2 Maximal Coverage Problem

The maximum coverage location model has been used widely in analyzing locations for public service facilities by trying to optimally locate servers so as to maximize the expected coverage of demand. An example is trying to locate a fire or police station such that it can serve the most number of residents. Daskin (11:48) extended that model to account for the chance that when a demand arrives at the system it will not be covered since all facilities are engaged serving other demands. In the maximal coverage location problem, nodes are weighted according to the demands generated at the nodes, and in the set covering problem all nodes are weighted equally. Daskin also states that it is worth noting that restricting facility locations to nodes on the network has resulted from a simplifying assumption that was designed to make these type of problems computationally feasible. "Location on the nodes only, may not be optimal" (11:49). The traditional maximal coverage location model formulated by Daskin is as follows:

$$\text{Maximize} \sum_k h_k y_k \tag{2.11}$$

subject to:

$$y_k - \sum_i a_{ki} X_i \leq 0 \quad k = 1, \ldots, N \tag{2.12}$$

$$\sum_i X_i \leq M \tag{2.13}$$

$$X_i = 0, 1 \quad i = 1, \ldots, N \tag{2.14}$$

$$y_k = 0, 1 \quad k = 1, \ldots, N \tag{2.15}$$

where:

h_k = demand generated at node k

$$y_k = \begin{cases} 0 & \text{if node } k \text{ is not covered} \\ 1 & \text{if node } k \text{ is covered} \end{cases}$$

$$X_i = \begin{cases} 0 & \text{if a facility is not located at node } i \\ 1 & \text{if a facility is located at node } i \end{cases}$$

$$a_{ki} = \begin{cases} 0 & \text{if } d_{ki} > D\text{–a facility at } i \text{ does not cover demands at } k \\ 1 & \text{if } d_{ki} \leq D\text{–a facility at } i \text{ covers demands at } k \end{cases}$$

M = number of facilities to be located

N = number of nodes in the network

The objective function in this formulation maximizes the demand that is covered. The first constraint states that node k cannot be covered unless at least one of the facilities is located at one of the nodes i which cover node k. The second constraint states that at most M facilities are to be located and generally this constraint will be binding.

Developing upon this maximal expected covering location problem is Batta and Dolan (1) who build into the model the possibility that a server may be unable to respond to a new demand because they are answering another call. They discuss three ways of improving upon Daskin's solutions and techniques:

- use a post-integer program analysis procedure
- use the adjusted maximal expected coverage location problem objective function (correction factors)
- use the hypercube optimization procedure

The use of a maximal service distance as a measure of the value of a given locational configuration has been thoroughly discussed by Toregas and ReVelle (27) who show that it is an important measure of the value of a given locational configuration. For a given location solution, the maxi-

mum distance which any user would have to travel to get to a facility would show the worst possible performance of the system. As an example, the maximal service distance has been used often in the regional location of emergency facilities such as fire stations or ambulance dispatching stations. However, it is possible that a solution may yield a distance value larger than a maximum desired distance, say S. If that is the case, the decision maker may shift his attention to the total population covered within S. Since the resources are insufficient for total coverage within the distance desired, the decision maker may try to cover as much as possible within the given distance, S, using his limited resources. In other words, if there is not enough facilities for total coverage within the desired distance constraint, he will try to locate the facilities such that as few people as possible lie outside the distance, S.

This type of problem is known as a Maximal Covering Location Problem and is formulated as follows:

$$\text{Maximize } z = \sum_{i \in I} a_i y_i \tag{2.16}$$

subject to:

$$\sum_{j \in N_i} x_j \geq y_i \quad \forall \quad i \in I \tag{2.17}$$

$$\sum_{j \in J} x_j = P \tag{2.18}$$

$$x_j = (0,1) \quad \forall \quad j \in J \tag{2.19}$$

$$y_i = (0,1) \quad \forall \quad i \in I \tag{2.20}$$

where:

$I =$ denotes the set of demand nodes

$J =$ denotes the set of facility sites

$S =$ the distance beyond which a demand point is considered "uncovered" (the value of S can be chosen differently for each demand point if desired)

d_{ij} = the shortest distance from node i to node j

$$x_j = \begin{cases} 1 & \text{if a facility is allocated to site } j \\ 0 & \text{otherwise} \end{cases}$$

$$y_i = \begin{cases} 1 & \text{if a demand exists at demand node } i \\ 0 & \text{otherwise} \end{cases}$$

$N_i = \{j \in J | d_{ij} \leq S\}$

a_i = population to be served at demand node i

p = the number of facilities to be located.

Chan, Forgues, and Kelso(8) show a variation of the p-median problem where one attempts to place p facilities among K demand points and minimize the average distance or time between facility and serving locations. This generalizes the formulation to include demand at various states of the system. This maximal coverage problem is expressed as:

$$\text{Max} \sum_{i}^{|I|} \sum_{j}^{|J|} \sum_{k}^{K} w_{ijk} x_{ijk} \tag{2.21}$$

subject to:

$$y_j - x_{ijk} \geq 0 \quad \forall\ i,\ j\ ,k \tag{2.22}$$

$$\sum_{j}^{|J|} y_j = p \tag{2.23}$$

$$\sum_{j}^{|J|} w_{ijk} x_{ijk} \geq d_k \quad \forall i, k \tag{2.24}$$

$$x_{ijk} = \{0, 1\} \tag{2.25}$$

$$y_j = \{0, 1\} \tag{2.26}$$

where:

i represents the demand, that is the satellite requiring imaging, which is a member of the set I;

j represents the facility, that is the radar site that is doing the imaging, which is a member of the

set J;

k is the time period, in this case the month;

w_{ijk} is the frequency of observations of satellite i by station j in month k;

x_{ijk} is a binary decision variable that describes whether satellite i was imaged by radar site j in month k;

y_j is a binary indicator that describes whether a facility is in place or not;

d_k is the required number of observations of a satellite by a radar during month k; and

p is the number of facilities to be located.

The authors note that "rather than an all-or-nothing assignment of facility to a demand, several facilities can be used to satisfy the demand."(8:5)

2.3 Networks

The Chan et al. (8) paper goes on further to present the maximal coverage and set covering problems as a network with gains model. They note that although p-median problems have been represented by bipartite graphs, the inclusion of the costs of serving demands in various states in the coverage constraint destroys total unimodularity in the constraint matrix and eliminates the use of a pure network construction(8:7). They thus introduce a generalized network (network with gains) and demonstrate a solution to the maximal coverage problem using three demands and three facilities in three states. A solution is given for $p = 1, 2, 3$ facilities to be located.

An assumption taken by this paper is that "network algorithms are computationally more efficient than regular integer linear programming techniques." (8:11) However, given that total unimodularity is no longer present, it is wondered if the network with gains formulation will still yield an integer solution.

In a thesis by Forgues (13) several methods were used to obtain integrality. Again it was noted that a pure network flow formulation could not be obtained(13:42). Using a network flow package,

Forgues confirmed that the solution using network flow programming would not necessarily yield an integer solution since the node-arc incidence tableau was not totally unimodular.

Forgues went on to modify the maximal coverage equations into a network flow with gains formulation for inclusion in a mixed integer programming package (MIP83). The MIP83 output was forced to be integer by using a branch and bound solution methodology. Forgues then took the network flow formulation and added three types of side constraints (13:42) to force integrality. This Linear Programming (LP) formulation did indeed yield integer results. The Forgues thesis confirmed that networks could be used to model the maximal coverage location problem.

2.4 Definitions and Terminology

2.4.1 Networks The following definitions are from Chan (6) and Nemhauser(23).

2.4.1.1 Graph. A graph, $G(V, E)$, is a set of nodes $V = \{1, 2, \ldots, m\}$ connected by edges $E = \{e_1, e_2, \ldots, e_n\}$.

2.4.1.2 Network. A network is a graph with flow of some kind.

2.4.1.3 Unimodular A square, integer matrix is called unimodular if its determinant, $\det(B) = \pm 1$. An integer matrix A is called totally unimodular (TU) if every square, non-singular submatrix of A is unimodular.

2.4.1.4 Source/Sink. A source in a network is a node where units of flow enter the network. Conversely, a sink in a network is a node where units of flow leave the network. Networks can be designed with multiple sources and sinks.

2.4.1.5 Pure/Generalized Networks. In a pure network, there are no losses or gains of units of flow through the network. That is, for every unit of flow entering the network, there is only one unit of flow leaving the network. Conversely, in a network with gains (one type of generalized

network), losses or gains can be modelled to occur at nodes and/or arcs. This gain/loss can be integer or fractional. The flow in and/or out of the network at a given node can be fixed or variable.

2.4.1.6 Theorems. If matrix A is TU, then all of the vertices of the polyhedron $P(b) = \{x \in R^n_+ : Ax \leq b\}$, are integer for any integer vector b, $b \in Z^m$. That is, an integer solution can be obtained to a linear program without the need to impose integer restrictions on the variables when the constraint matrix A is TU.

An integer matrix A with all elements $a_{ij} = 0, \pm 1$, is TU if no more than two non-zero entries appear in any column, and if the rows of A can be partitioned into two sets, Q_1 and Q_2 such that:

1. If a column has two entries of the same sign, their rows are in different sets Q_1 and Q_2, and
2. If a column has two entries of different signs, their rows are in the same set Q_1 or Q_2.

2.4.2 Imaging Radar. The most basic method of radar imaging involves discrimination on the basis of range. The determination of range is done by measuring the time delay between a distinct feature present in the transmitted radio waveform and also present and recognizable in the returned radio waveform. Calculation of the range is done using knowledge of the propagation velocity through the medium. One of the means of measuring range is with the pulsed radar "in which the leading and trailing edges of the pulse provide inherent time markers."(21:7) The round-trip propagation delay for a reflecting target at a range R is given by $2R/c$, where c is assumed to be the propagation velocity. The radar pulse duration can then determine the minimum distance two points must be separated by (resolution) in order to produce distinguishable radar returns. The range increment is given by $\Delta R = cT/2$ where T is the pulse duration. The resolution is defined as the ability to distinguish closely spaced objects. Range accuracy can be increased by using wide bandwidths and high power radars.

Spatial resolution can be measured by synthetic means when the results of many observations of the target at differing frequencies and angles are coherently combined. Synthetic in this

context is defined as the "synthesis of short-pulse, narrow-beam radar performance from elemental measurements."(21:7)

Radar cross section (RCS) imaging refers to the "effective echoing area of a target."(29:17) Using the concept of an imaginary spherical surface that represents the target, the RCS is further defined as "the area on the sphere's surface at the target position that isotropically reradiates all of its incident power at the same radiation intensity (power per unit solid angle) as the target reradiates toward the radar receiver."(29:17) A high degree of RCS can be had by scanning a focused beam across the target. The minimum lateral extent of the scanning beam, which can be described as an aperture which forms the scanning beam is approximately given by:

$$\Delta = \lambda R/D \tag{2.27}$$

where:

λ = wavelength

D = aperture dimension

R = observation distance

Radar resolution is similar to optical systems in that resolution is limited by the Raleigh resolution criterion, which states that the minimum resolution that can be expected of two adjacent targets lying in a plane normal to the line-of-sight of the radar beam is given by the spot dimension, Δ(21:15). The radar aperture is synthetic unlike optical systems and is called synthetic aperture radar (SAR). SAR can achieve even higher resolution in the cross-range direction by using the motion of the vehicle carrying the radar (usually an aircraft) to synthesize the effect of a large antenna aperture. This has been applied in aircraft mapping of ground areas.

If the radar is not moving, then another method must be used to synthesize the aperture. This is accomplished by viewing a target that is rotating and thus providing the necessary changes in viewing angles. This is called inverse synthetic aperture radar (ISAR). Inverse refers to the synthetic

aperture being formed by the rotation of the target rather than by the rotation or movement of the radar. The cross-range resolution of the target is then given by:(21:16)

$$\Delta = \lambda R/2D = \lambda/2\sin(\Theta) \tag{2.28}$$

where:

Δ is cross range resolution

λ is wavelength of the radar

D is the equivalent aperture dimension

R is the distance to the target

Θ is the angle through which the target has rotated

Note that the range and aperture dimension can be eliminated from the RCS equation, providing there is enough power to provide a radar return, and is given by an angular rotation of the object. The cross range resolution can be obtained synthetically by processing the signals that are scattered form the target at various viewing angle to provide for angular diversity. As mentioned, this requires relative motion between the radar and the target in order to produce changes in the relative aspect angle. The resolution is in the plane of the angular motion in a direction perpendicular to the line-of-site.

An imaging radar such as the Haystack radar at MIT, relies upon ISAR and the effective angular rotation of the satellite. The required power mentioned earlier is not a problem with the Haystack radar since it has enough power to image a satellite in Geostationary orbit, providing the satellite is rotating(4:1). The Haystack radar operates in the X-band at 10 GHz (5:4).

Generally, radio waves tend to be dissipated by large quantities of moisture in the atmosphere (heavy rain). However, as one increases the frequency of the radar, one can reduce moisture effects to an insignificant level except in the very heaviest of rainfall conditions(26:270). Thus for 10 GHz, rainfall in the Canadian environment is not a factor in site location. However, the higher

the frequency of the radar, the more the atmosphere attenuates the signal. The Haystack radar overcomes this by its large power output and can operate unimpeded providing the beam is at five degrees or higher elevation(4:3).

Wind can significantly affect a radar's precision pointing performance and thus significantly degrade its RCS resolution. Skolnick notes that this factor has been discounted through the prevalent use of protective radomes(26:269).

2.4.3 Orbit Types

2.4.3.1 Sun Synchronous Orbit. The orientation of the orbit of a sun synchronous satellite is such that the orbital plane remains fixed with respect to the sun. This has the advantage of always placing the satellite over a specific spot on the ground at the same time each day. Because the earth revolves around the sun, the orbit must precess at an easterly rate of 0.9856 degrees per day(24:45) to maintain the same path-time performance. The precession of the satellite is caused by the fact that the earth is not a perfect spheroid. Thus the orbital inclination is chosen such that the desired precession is achieved(2:157).

2.4.3.2 Earth Synchronous Orbit. Whenever a satellite's orbit is such that it completes an integer number of orbits per sidereal day, it is considered to be earth synchronous(24:46). One special case is when the number of orbits is one. A circular orbit with an inclination of zero degrees is called geostationary and appears to hover motionless over one spot on the equator. Geostationary satellites are not considered in this research since they generally are just for communication purposes and are too high ($19,300$ NM above the earth's surface) for useful spy missions.

Another type of earth synchronous satellite orbit is the Molniya orbit. Molniya orbits complete two revolutions per sidereal day and are thus semi-synchronous. The Molniya orbit is generally used by what was called the Soviet Union for communications satellites(24:44) but is considered a

target in this research because its highly elliptical orbit brings the satellite quite close to the Earth during part of its orbit.

2.4.4 Coordinate Systems. When referring to positions of satellites and positions on the earth's surface, one must have a reference frame within which to place an object's location. The following definitions are paraphrased from MECH 532, Fundamentals of Astrodynamics class notes and Bates, Mueller, and White(2).

2.4.4.1 Earth Centred Inertial (ECI). Also referred to as the **IJK** reference frame, the ECI has its origin at the earth's centre. The fundamental **X-Y** plane is the equator with the positive **X**-axis, or **I** unit vector, pointing towards the first point of Aires (vernal equinox direction). The **Z**-axis, or **K** unit vector points in the direction of the North pole, normal to the **X-Y** plane. The ECI reference frame does not rotate with the earth, but assumes inertial properties by remaining fixed with respect to the stars, and the earth rotates with respect to this frame.

2.4.4.2 Perifocal Coordinate System. The perifocal coordinate system uses the orbital plane of the satellite as its basis. The orbit of a satellite is an ellipse with the centre of the Earth located at one of its foci. The origin of this coordinate frame is located at this foci with the **P** unit vector pointing from the origin towards the periapsis in the orbital plane. The **Q** unit vector is rotated 90 degrees in the direction of orbital motion and is also in the orbital plane. The **W** unit vector completes the right-handed coordinate system and is normal to the orbital plane since it is perpendicular to both the **P** and **Q** unit vectors. In the perifocal coordinate system the satellite does not have any components of position or velocity in the **W** direction.

2.4.4.3 Satellite Coordinate Frame. A reference frame can be chosen for any system to accomplish a given task or to simplify a computation. In this case, to calculate effective angle of rotation, a reference frame was created with regards to the satellite. The $\mathbf{b_1}$ unit vector is chosen such that it lies directly along an extension of the line from the centre of the Earth to the satellite.

The $\mathbf{b_3}$ unit vector lies parallel to and in the same direction as the specific angular momentum vector, $\mathbf{h}$. The remaining unit vector, $\mathbf{b_2}$, is calculated by doing a cross product between the $\mathbf{b_3}$ and $\mathbf{b_1}$ vectors. This right-handed coordinate system thus consists of three mutually perpendicular vectors as do the other coordinate frames.

2.4.4.4 Geodetic Reference System. Man commonly navigates along the surface, or slightly above the surface[1] of the Earth with respect to a series of concentric imaginary circles parallel to the equator (lines of latitude) and normal to the equatorial plane (lines of longitude). The lines of latitude are referenced in degrees North or South of the equator with the equator being zero degrees; and the lines of longitude are referenced in degrees East or West of the Greenwich Meridian, an arbitrarily chosen line of longitude running through Greenwich, England. The geodetic reference system is referenced to the ECI system by an angle between the vernal equinox direction and the Greenwich Meridian, θ_g, which is referred to as Greenwich Sidereal Time. Although it is an angle, it is referenced as a time by comparing the passage of time since the Greenwich Meridian was last incident upon the **I** unit vector.

2.4.5 Classical Orbital Elements The following are definitions of the classical elements used in the calculations of satellite and radar site positions in the course of this research. The definitions are derived from Bates et al. (2)

2.4.5.1 Semi-Major Axis, a. The semi-major axis is a constant defining the size of the conic orbit, in this case the conic section being an ellipse.

2.4.5.2 Eccentricity, e. Eccentricity is another constant describing a conic section. e describes the shape of the conic orbit.

[1] Relative to the size of the Earth.

2.4.5.3 Inclination, i. i is the angle between the angular momentum vector, **h**, and the **K** unit vector from the ECI coordinate frame.

2.4.5.4 Longitude of the Ascending Node, Ω. This is the angle measured in the **I-J** plane between the **I** unit vector and the point where the satellite orbit crosses through that plane in a northerly direction (ascending node) measured counterclockwise when viewed from the positive **K** side of the **I-J** plane.

2.4.5.5 Argument of Periapsis, ω. This is the angle measured in the plane of the orbit and in the direction of the satellite's motion, between the ascending node and the periapsis point. The periapsis is the point of the orbit that is close to the Earth and is coincident with the **P** unit vector. For an Earth centred orbit, ω can also be called argument of perigee.

2.4.5.6 Time of Periapsis Passage, T. T is the time when the satellite was at periapsis.

2.4.5.7 True Anomaly at Epoch, ν_o. The epoch, t_o is a stated time where the position of the satellite was known or measured. The true anomaly at epoch is the angle measured in the orbital plane between periapsis and the position of the satellite at t_o.

2.4.6 NORAD Element Sets The NORAD[2] two-line element set is a description of the orbit of a satellite at a given point in time as a result of a series of observations (radar or optical) while tracking that satellite. Orbits of satellites do change as a result of moon and sun gravitational effects, air drag, and orbital manoeuvreing (rocket propulsion), to name a few perturbations. An example of a NORAD two-line element set is given below with a description excerpted from Dr T.S. Kelso's PASSCHED program instructions(18).

```
1 20452U 90  8  A 90191.64282447  .00000001  00000-0  99999-4 0   808
```

[2] North American Air Defence

```
2 20452  54.5508 255.0660 0027829  44.9864 315.3289  2.00872988  3311
```

Line 1

Column	Description
01-01	Line Number of Element Data
03-07	Satellite Number
10-11	International Designator (Last two digits of launch year)
12-14	International Designator (Launch number of the year)
15-17	International Designator (Piece of launch)
19-20	Epoch Year (Last two digits of year)
21-32	Epoch (Julian Day and fractional portion of the day)
34-43	First Time Derivative of the Mean Motion or Ballistic Coefficient (Depending on ephemeris type)
45-52	Second Time Derivative of Mean Motion (decimal point assumed; blank if N/A)
54-61	BSTAR drag term if GP4 general perturbation theory was used. Otherwise, radiation pressure coefficient. (Decimal point assumed)
63-63	Ephemeris type
65-68	Element number
69-69	Check Sum (Modulo 10) (Letters, blanks, periods, plus signs = 0; minus signs = 1)

Line 2

Column Description

01-01	Line Number of Element Data
03-07	Satellite Number
09-16	Inclination [Degrees]
18-25	Right Ascension of the Ascending Node [Degrees]
27-33	Eccentricity (decimal point assumed)
35-42	Argument of Perigee [Degrees]
44-51	Mean Anomaly [Degrees]
53-63	Mean Motion [Revs per day]
64-68	Revolution number at epoch [Revs]
69-69	Check Sum (Modulo 10)

III. Conventional Methodology

The purpose of this chapter is to examine conventional procedures that can be used to solve facility location problems that are formulated as a maximal coverage problem.

3.1 Conventional Approaches to the Problem

3.1.1 The Maximal Coverage Problem. Following the work by Forgues(13), a maximal coverage problem was set up. However, instead of initially formulating the problem as a network and then using a branch and bound solution, the problem was formulated as a modified maximal coverage problem similar to the formulation given by Chan et al. (8:5). This maximal coverage problem is a variant of the generalized p-median problem and is given by the following:

$$\text{Maximize} \sum_{i}^{|I|} \sum_{j}^{|J|} \sum_{k}^{K} w_{ijk} x_{ijk} \tag{3.1}$$

subject to:

$$y_j - x_{ijk} \geq 0 \quad \forall\ i,\ j,\ k \tag{3.2}$$

$$\sum_{j}^{|J|} y_j = p \tag{3.3}$$

$$\sum_{j}^{|J|} w_{ijk} x_{ijk} \geq d_k \ \ \forall i, k \tag{3.4}$$

$$x_{ijk} = \{0, 1\} \tag{3.5}$$

$$y_j = \{0, 1\} \tag{3.6}$$

where:

- i represents the demand, that is the satellite requiring imaging, which is a member of the set I;

- j represents the facility, that is the radar site that is doing the imaging, which is a member of the set J;
- k is the time period, in this case the month, out of the set of K periods;
- w_{ijk} is the frequency of observations of satellite i by station j in month k;
- x_{ijk} is a binary decision variable that describes whether satellite i was imaged by radar site j in month k;
- y_j is a binary indicator that describes whether a facility is in place or not;
- d_k is the minimum required number of observations of a satellite by a radar during month k;
- and p is the number of facilities to be located.

Equation 3.2 states that a satellite cannot be imaged from a site unless that radar site exist. Equation 3.3 stipulates the number of radar sites that will be built. The minimum number of observations constraint, equation 3.4, is desired, but if it results in an infeasible solution, it can be relaxed.

3.1.2 Knapsack Formulation. A potential formulation of the problem is to include only one constraint in addition to the nonnegativity constraints. This type of problem is called a ***knapsack problem*** and has computational advantages over other methods when the problem involves only one constraint. To formulate the above maximal coverage problem as a knapsack problem, one would combine the weights for each demand over all of the states in terms of each facility:

$$a_j = \sum_{i}^{|I|} \sum_{k}^{K} w_{ijk} \tag{3.7}$$

Equation 3.7 would then define the number of observations for a given facility over all states for all satellites. The new formulation would be given as:

$$\text{Maximize} \sum_{j}^{|J|} a_j y_j \tag{3.8}$$

subject to:

$$\sum_{j}^{|J|} y_j \leq p \quad \forall\ j \tag{3.9}$$

$$y_j = \{0, 1\} \tag{3.10}$$

where:

- j represents the facility, that is the radar site that is doing the imaging, which is a member of the set J;
- y_j is a binary indicator that describes whether a facility is in place or not;
- and p is the number of facilities to be located.

This formulation assumes that d_k, the minimum required number of observations of a satellite by a radar during each designated time period can be satisfied by any choice of p locations or can be accounted for in the derivation of the a_j parameters or exclusion of some potential sites in a pre-filtering of the data before inclusion in the formulation. That is, if a radar site has not met the minimum number of observations criteria, then that site is not included in Equation 3.8.

The disadvantage to the knapsack problem is that it may not be possible to add additional constraints in future computations should the decision maker choose to do so. Thus, the modified maximal coverage problem as given by Chan et al. (8) was used in the development of this imaging radar facility location problem.

3.2 Computational Complexity

Many different methods and algorithms have been devised for the solution of optimization problems since the advent of Dantzig'z simplex method. One of the reasons for this proliferation of methods is to try to decrease computational complexity and arrive at the optimal solution faster and more efficiently. However, not all methods can be applied to all problems, and while more than one method may be applied to some problems, the decision maker would prefer to use the most efficient solution methodology.

Computational complexity describes how difficult a problem *may* be to solve in a worst case problem. In most cases, the solution does not use as many steps as it could. For example, the Dantzig simplex method could visit the potentially exponential number of veritices in a matrix A of size $m \times n$. The potential number of calculations can be at least 2^m whenever $n \geq 2m$ (3:375), or in other words, exponetial. In practice, the usual number of iterations has been observed to be $3m/2$, and seldom more than $3m$ iterations. However, the exponential case does exist, and has been shown to take as many as $2^n - 1$ iterations(3:376).

Where the desired output of a problem is binary, a facility is to be located, or it is not, the general problem, $\max\{cx : Ax \leq b, x \in B^n\}$, can be solved by a brute-force enumerative alogorithm. However, this type of solution is not very efficient and can take $O(2^n mn)$ time to solve(23:125). More efficient methods such as the ***integer knapsack problem*** can be solved using some algorithms in as little as $O(nb)$[1]. However, even this method can be exponential unless b is restricted to be a polynomial function of n(23:125). Another conventional integer solution methodology is the Branch and Bound. However, the potential number of iterations for this method can be exponential, $O(2^n)$. In contrast, the complexity of a network algorithm can be $O(m^2)$ or $O(m^3)$ (3:575).

[1] When all variable coefficients are equal to one in the constraint, then the knapsack problem can be a trivial IP to solve, by ordering $a_i y_j$ in non-increasing order and taking first p sites.

3.3 Baseline for Scaled Down Problem

Although the knapsack problem can be used to solve the maximal coverage problem for uncomplicated cases, and may be more efficient than a network algorithm in problems that are not excessively large, it was not used in this study. As general a solution method as possible was desired so that in future formulations of this problem the decision maker could add extra constraints if desired. Thus the problem was initially formulated as a modified maximal coverage problem to include states in the manner given by Chan et al. (8). A scaled down 'test' problem was was introduced and solved using a convential Branch & Bound algorithm using the MIP83 software package. The 'test' problem was designed to provide a smaller scale problem than the case study to aid in the development of the models and the understanding of the results. In this 'test' problem, the formulation is limited to $i = 4$ demand points (satellites), $j = 3$ supply facilities (radar sites), and $k = 3$ states. The weights used in the maximal coverage and in the network formulations are listed in tables 3.1, 3.2, and 3.3. The weights represent the number of times that a radar site j was able to image a given satellite i within a given time frame (state k). To simplify the notation from w_{ijk}, the states are combined with i and j to form w_{ij}. Thus satellites 10 to 13 are in state 1; satellites 14, 15, 16, and 17 are satellites 10, 11, 12, and 13, respectively, in state 2; and satellites 18, 19, 20, and 21 are satellites 10, 11, 12, and 13, respectively, in state 3. Similarly, sites 1, 2, and 3 are in state 1; sites 4, 5, and 6 are sites 1, 2, and 3, respectively, in state 2; and sites 7, 8, and 9 are sites 1, 2, and 3, respectively, in state 3. The MIP83 maximal coverage formulation included the variable y_j to indicate whether a facility is in place or not. Since sites 1, 4, and 7 were the same facility, but in different states, an additional pair of equations was required that would force sites 1, 4, and 7 to all be either on ($y_j = 1$) or off ($y_j = 0$). Similarly, pairs of equations were added for sites 2, 5, and 8, and for sites 3, 6, and 9.

The purpose of the monthly observation constraints was to ensure that a minimum number of observations was obtained for each demand (satellite) for each time period (state). This constraint

Table 3.1. w_{ij} for State 1

w_{ij}	10	11	12	13	TOTAL
1	20	22	24	21	87
2	23	19	28	22	92
3	27	23	21	25	96
TOTAL	70	64	73	68	275

Table 3.2. w_{ij} for State 2

w_{ij}	14	15	16	17	TOTAL
4	21	27	25	21	94
5	21	23	23	23	90
6	19	28	26	26	99
TOTAL	61	78	74	70	283

was included in the MIP83 formulation to be true to the maximal coverage formulation presented earlier, but was not included in the network flow formulation later on. Leaving out this constraint means that the optimal location will be the site which provides the greatest throughput potential, serves the largest population, but may not image all satellites the minimum required number of times. In the 'test' problem, this was not the case. Theoretically, a satellite only needs to be imaged once to get the necessary image. However, a reconnaissance satellite may not always be pointing towards the Earth and may, on most passes, when no activity is expected on the ground, be pointed away from the Earth so that ground observations will not be able to determine its shape and purpose. The actual number of observations required in practice was classified and unavailable

Table 3.3. w_{ij} for State 3

w_{ij}	18	19	20	21	TOTAL
7	28	24	23	22	97
8	24	23	23	19	89
9	26	22	22	19	89
TOTAL	78	69	68	60	275

for this research. Thus, this constraint was not included in the network flow formulations presented later. These constraints did not affect the MIP83 solution.

The MIP83 input was an ASCII text file with a .LP extension. Output is normally directed to the screen unless the output option is exercised. The following line is typed at the MSDOS prompt while in the same directory as the MIP83.EXE program (and the text input file):

MIP83 *inputfilename*.LP OUTPUT *outputfilename.ext*

The .LP extension is assumed and does not need to be included. The output is an ASCII text file also.

The structure of the input file is described in detail in the LP83/MIP83 manual(20). Program input requirements begin with a ..TITLE statement followed by a title. The ..OBJECTIVE statement follows the title line, indicating whether the problem is a maximum or minimum. The objective function following this statement must include all variables used in the problem, including those that have a cost value of zero. Single square brackets around a variable indicate to the program that that variable is an integer. Double square brackets around a variable dictate that that variable will only be a binary variable (0, 1). Comments can be included by beginning the line with an asterisk. The constraints section begins with the ..CONSTRAINTS statement followed by the lines of input indicating the constraints. Format is simple with the equations being in normal mathematical form. Some mathematical symbols that are not available in ASCII form such as $\geq$ can be indicated by a combination of symbols such as >=.

Output is in ASCII format that can be viewed by a text editor or word-processor capable of taking ASCII input (very few are not capable of this).

The MIP83 formulation and solution for $p = 1$ is shown in Appendix C. The solution chose site three as the optimal solution with an objective function value of 284 satellites observations over the three states. The solution was integer as expected since MIP83 uses a branch and bound algorithm, which may not be computationally efficient(6), but does provide an integer solution.

The solution was confirmed by doing a manual enumeration of all three states for all three sites for all four satellites. Site 1 has a total of 278 imagings, site 2 had a total of 271 imagings, and site 3 had a total of 284 imagings.

A baseline was also established for $p = 2$ facilities to be chosen for the 'test' problem. The only change from the original MIP83 formulation was the change in the last equation from y1 + y2 + y3 = 1 to y1 + y2 + y3 = 2. The formulation and optimal solution of 562 imagings using sites one and three is shown in Appendix R. The optimal solution shows the total sum of the number of imagings by both chosen sites. No penalty or benefit is assessed by having more than one site image the same satellite. This is a result of the maximal coverage formulation.

IV. Network Methodology

The maximal coverage location problem is generally formulated as a linear programming problem with some of the variables being binary, hence making it a mixed integer programming problem. According to the SAS/OR manual(25:358) and OPER 767 class notes(6), if the linear programming program contains large embedded network structures, then that problem can be formulated as a network flow problem and computational complexity decreases. The problem should ideally be formulated as a pure network flow, but due to the inclusion of states, this problem was formulated as a network with gains. Work by Forgues (13:42) was not able to provide a pure network flow out of a similar maximal coverage problem, but the generalized network with gains that was used was still more computationally efficient than mixed integer linear programming solution algorithms. In this paper, the number of facilities, demands, and states is not sufficiently large enough to prove this assumption.

A graphical summary of the method evolution for the 'test' problem is shown in Figure 4.1.

4.1 Network With Gains

The 'test' problem was reformulated as a network with gains and an attempt was made to integerize the solution. As in Forgues' case (13:42), an integer solution was not achieved. However, this method was used to show that a fortunate choice of weights had not inadvertently generated an integer solution, thus tainting any other solution methods.

The generalized network with gains model is shown in Figure 4.2. The subscripts describing the flow are reversed from the maximal coverage problem. These subscripts are in keeping with convention for flows describing arcs, i.e. $x_{1,10}$ is flow from node 1 to node 10.

The network shows three radar sites in three different states: nodes 1, 4, and 7 represent radar site 1 in states (months) 1, 2, and 3, respectively; nodes 2, 5, and 8 represent radar site 2 in states 1, 2, and 3, respectively; and nodes 3, 6, and 9 represent radar site 3 in states 1, 2, and

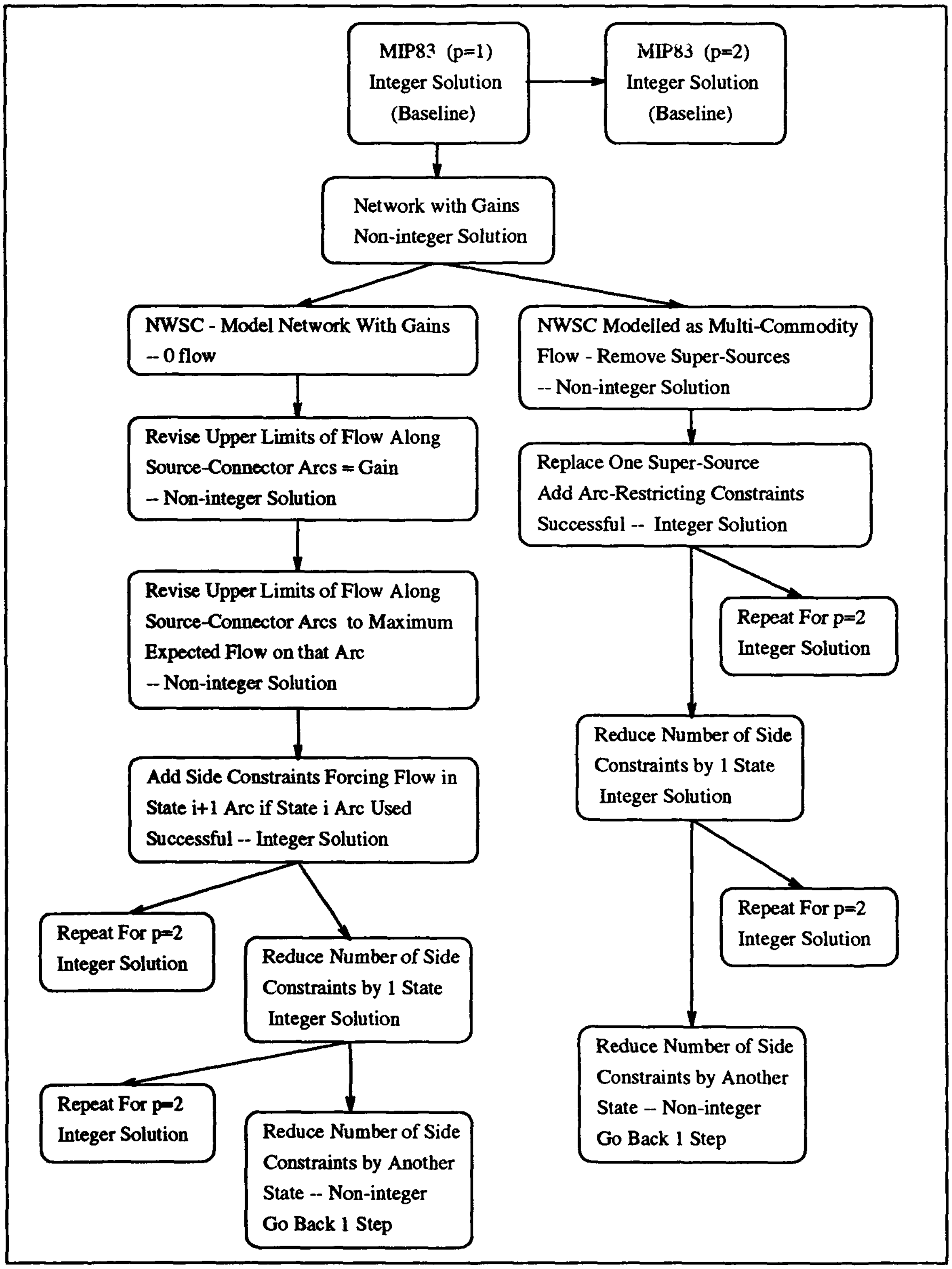

Figure 4.1. Evolution of Solution Methodology

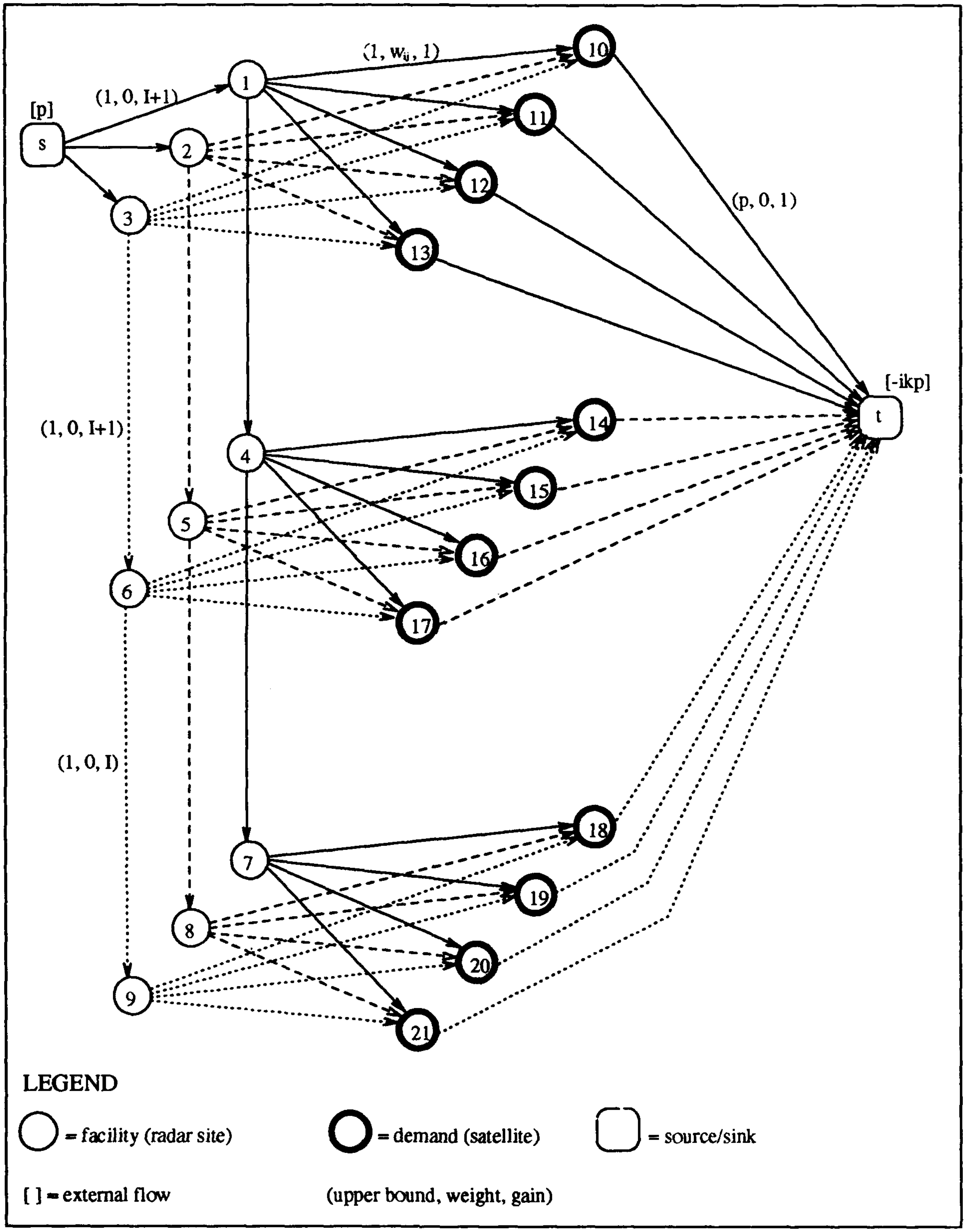

Figure 4.2. Maximal Coverage Network With Gains

3, respectively. The four satellites are represented by nodes 10, 11, 12, 13 (state 1); 14, 15, 16, 17 (state 2); 18, 19, 20, and 21 (state 3).

The external flow at the source is fixed equal to the number of radar sites to be built, p. The arcs connecting the source (s) to the radar sites (facilities, j) have a capacity of one, cost of zero, and a gain of $|I| + 1$ (i.e. $4 + 1$). The arcs connecting the facilities between states have similar parameters to those arcs emanating from the source, except for the arcs connecting state $K - 1$ to state K, which have a gain of only $|I|$. The arcs connecting the satellites with the radar sites in the same state, have a capacity of one, cost equivalent to the number of times observed (w_{ijk} shortened to w_{ij}), and gain of one. Finally, the arcs connecting the satellites in all states with the sink node, t, have a capacity of p, cost of zero, and gain of one. The fixed external flow out of the sink node has a value equivalent to the number of facilities desired multiplied by the number of satellites and the number of states ($-p \times i \times k$).[1] In this example, the fixed external flow out of the sink node is equal to $-(1 \times 4 \times 3) = -12$.

The total number of observations for this example for all of the radar sites with the satellites is the same as for the MIP83 formulation in the preceding section.

For a problem with $|I|$ demands, $|J|$ locations, and K states, the number of nodes is given by $2 + k \times (i + j)$. That is, the number of states multiplied by the total number of demands and locations in each state plus two extra nodes for the source and sink. In this problem the total number of nodes is $2 + 3 \times (4 + 3) = 38$.

The total number of arcs in the network is given by the sum of the number of arcs out of the source (j), plus the number of arcs into the sink ($i \times k$), plus the total number of arcs connecting the facility and demand nodes in the various states ($i \times j \times k$), plus the number of 'inter-state' arcs ($j \times (k-1)$). This reduces to $k \times (i+j+(i \times j))$ and for this problem equates to $3 \times (4+3+4 \times 3) = 57$

[1] The minus represents external flow out of a node.

arcs. For the case study later ($i = 16$, $j = 12$, $k = 3$), a formulation of this type would result in 86 nodes and 660 arcs.

4.1.1 Solution Procedure Using MICROSOLVE Network Flow Programming The MICROSOLVE Network Flow Programming software package for the PC was used to attempt to solve this problem. The generalized network portion of the program was easy to use although input tended to be long due to the requirement to enter zero values for many inputs. The MICROSOLVE User Manual(16) covers the operations and the inputs to the program. Basically, after specifying the number of arcs and nodes, the values for costs (weights), capacities, external flows, and gains were filled in. The weights were assigned negative values since the program is doing a minimization. The network is identical to that shown in figure 4.2 although a graphical depiction was not given.

The resulting output is shown in Appendix D with an optimal solution of approximately 301. The flows along the selected arcs were not integer and thus were difficult to interpret. Overall, the most number of satellites that were imaged by any one site was by site three as shown by six facility to satellite arcs reaching the upper flow limit. Site two had one demand satisfied and site one had five demands reaching the upper flow limit. Site three received the largest flow initially from the source node, thus agreeing with MIP83's choice of site three as the optimal solution for this set of weights. This type of inference may not be true in general, but appeared to be valid in this case.

4.2 Network With Side Constraints - Simulated Gains

In an attempt to take advantage of the unimodular nature of the network formulation, a network with side constraints procedure was adopted. The side constraints were added to force an integer solution that was not obtained by using the network flow with gains formulation. The SAS manual summarizes the efficiency and complexity issues of this type of formulation(25:358,359):

> Although PROC LP can solve network problems, the NETFLOW procedure generally solves network flow problems more efficiently than PROC LP.

When the network part of the problem is large compared to the non-network part, especillay if the number of side constraints is small, it is worthwhile to exploit this structure in the solution process.

Three types of constraints suggested by Chan et al. (8:12) were added to the network tableau for the maximal-coverage formulation. 'Source-connector flow' constraints force an upper bound of one on the flow through each of the first layer of arcs:

$$x_{sj} \leq 1 \qquad j = 1, 2, \ldots, |J| \tag{4.1}$$

The 'sink-connector flow' constraints are in place to ensure that the flow through each of the 'sink-connector' arcs is set equal to the number of facilities to be built, p:

$$x_{it} - p = 0 \qquad i \in \{\text{ demand nodes}\} \tag{4.2}$$

The 'equi-distribution of flow' constraints are introduced to ensure that the amount of flow entering the facility-location node via the 'source-connector' arc is matched by each of the arcs leaving that facility-location node:

$$x_{ji} - x_{sj} = 0 \qquad \forall\, i,\, s \in \{\text{ nodes adjacent to j }\};\, i \neq s \tag{4.3}$$

Equation 4.3 requires one pair-wise constraint for each facility-demand arc; in this case, five pair-wise constraints for facility nodes 1, 2, 3, 4, 5, and 6, and four pair-wise constraints for facility nodes 7, 8, and 9. 's' in this equation refers to any node preceding a facility node, such as another facility node from a preceding state. Similarly 'i' can be any node immediately after a facility node, such as a demand node or another facility node in the next immediate state.

Forgues showed in his example(13:47) that when these additional constraints were added to the maximal coverage formulation and run in LP83, a linear programming package, an integer solution was obtained which corresponded to the MIP83 solution.

The maximal coverage formulation was rewritten as a network with gains formulation and combined with the new constraints(Annex V). All of the equations were placed in tableau form to see if a network with a unimodular tableau could be found. The resulting tableau did appear to have a unimodular appearance providing the equations with the gains were ignored. Thus, the equations containing the gains were considered ideal to use as side constraints while the remaining equations formed a network without gains. This new formulation was prepared for input into SAS/OR on the VAX network at AFIT. The NETFLOW algorithm was called through the use of the command PROC NETFLOW. Although a linear programming program could be used to solve this sort of problem, the NETFLOW procedure generally solves network flow problems more efficiently than linear programming(25:358). A description of a network with side constraints algorithm is given in Kennigton and Helgason(19:166).

Equation 4.1 was not required as a separate set of constraints since it could be incorporated into the capacity or upper bounds of the source-connector arcs in the NETFLOW formulation.

The first NETFLOW formulation attempted was a direct implementation of the tableau developed above. The network resembled the network with gains network, except there were no gains along the network arcs (0's and 1's in the node-arc incidence matrix). The side constraints were used to attempt to induce the gains. Appendix E shows that the net result was zero flow. This is because the flow on all of the arcs is limited to one, and the side constraints require a flow into the facility node that equals five times the sum of the flows leaving that node. This is correct for a network with gains, but breaks the conservation of flow rule for a pure network. Thus the only feasible solution is zero flow.

The second NETFLOW formulation substituted the gains for an equivalent capacity of flow along the 'source-connector' arcs. Thus, where a gain of five had been before, the upper bound on that arc was now five vice one. The upper bounds were changed to five on arcs x_{s1}, x_{s2}, x_{s3}, $x_{1,4}$, $x_{2,5}$, and $x_{3,6}$, and to four on arcs $x_{4,7}$, $x_{5,8}$, and $x_{6,9}$. The side constraints were modified to reflect the arc capacity changes, which now resulted in 'flow in equals flow out.' The resulting SAS formulation and selected SAS output are shown in Appendix F. The maximum flow value was 300, however, the results were not as desired. Instead of the flow going through only one facility-location node in its various states, it had chosen a route that went through all three facility-location nodes and through all of the corresponding state 2 facility-location nodes. Only one of the third state facility-location nodes was used. Analysis showed that this formulation would not permit the desired tree type flow from one of the state one facility-location nodes. There was not enough flow coming from the source node to fill all of the arcs in the desired tree. Thus another formulation was required.

It was determined that to fill all of the arcs in the desired tree, a capacity of twelve ($j \times k$) was required for the three arcs emanating from the source node. Thus if all of the flow was to go through one of the state one facility-location nodes, all of the arcs entering the sink node could be filled to capacity (p), providing of course that the interstate arcs also had the correct capacity. The capacity for the arcs joining the state one to state two facility-location nodes was raised to eight ($j \times (k-1)$), while the state two to state three connecting arcs remained at an upper bound of four ($j \times (k-2)$). The resulting SAS formulation and selected SAS output are presented in Appendix G. The maximum flow achieved was 301, however, as in the previous formulation, more than one of the state one facility-location nodes was used. An analysis of the side constraints showed that the side constraints in this formulation were just a repetition of the information contained in the

pure network. This was confirmed by removing the side constraints[2] and rerunning the program (Appendix H). Identical results were obtained.

The side constraints were reformulated to force flow down a corresponding arc if an arc in a previous state had been used. Thus if arc $x_{s,1}$ was used, then arcs $x_{1,10}$, $x_{1,11}$, $x_{1,12}$, $x_{1,13}$, and $x_{1,4}$ must be used. For example:

$$-x_{s,1} + 12x_{1,10} = 0 \tag{4.4}$$

$$-x_{s,1} + 12x_{1,11} = 0 \tag{4.5}$$

$$-x_{s,1} + 12x_{1,12} = 0 \tag{4.6}$$

$$-x_{s,1} + 12x_{1,13} = 0 \tag{4.7}$$

$$-8x_{s,1} + 12x_{1,4} = 0 \tag{4.8}$$

Additional constraints for states two and three were added that permitted the flow to further cascade down the line. For example, $x_{1,4}$ having been forced to flow, $x_{4,14}$, $x_{4,15}$, $x_{4,16}$, $x_{4,17}$, and $x_{4,7}$ are also forced to flow.

$$-x_{1,4} + 8x_{4,14} = 0 \tag{4.9}$$

$$-x_{1,4} + 8x_{4,15} = 0 \tag{4.10}$$

$$-x_{1,4} + 8x_{4,16} = 0 \tag{4.11}$$

$$-x_{1,4} + 8x_{4,17} = 0 \tag{4.12}$$

$$-x_{1,4} + 2x_{4,7} = 0 \tag{4.13}$$

Similarly the state three flows were forced, with the only difference being that there is one less side constraint because there are no states beyond state three. The SAS formulation and selected SAS

[2]One constraint had to be in place for the program to run error-free. A redundant equation setting flow equal to maximum flow was used.

output are shown in Appendix I. The resulting maximum cost flow was 284 with the tree emanating from node three containing the maximum observations (same as for the MIP83 results).

This formulation, however, resulted in 42 side constraints, which was almost as numerous as the number of arcs (arcs = 58). The computational efficiency of the NETFLOW algorithm begins to degrade if the number of side constraints becomes too large(6). Since the flow was forced at states 1 and 2, it was postulated that perhaps the state 3 constraints were redundant and would not be required. Removing thes constraints resulted in twelve less side constraints, with thirty left. The resulting SAS formulation and selected SAS output are shown in Appendix J. The maximum flow and selected arcs were the same as for the full side constraint formulation, however, the status of those arcs and their reduced costs varied somewhat between the two formulations. At this point it is not known whether that is significant and would perhaps affect the answers for a similar problem with different numbers, or perhaps it was just the way the problem was solved based upon the reduced number of side constraints. The net result was however, the same, and should perhaps be explored further.

An attempt to further reduce the number of side constraints by removing the state two side constraints as well is shown in Appendix K. The non-integer results were surprising since the network formulations usually result in integer solutions. This suggested that only the last set of equations representing the last state could be eliminated.

The total number of arcs in the unimodular part of the formulation was the same as for the network with gains formulation except for an additional arc that was required to join the sink to the source at a cost of zero and unbounded capacity. Thus the total number of arcs was given by $1 + k \times (i + j + i \times j)$ and the total number of nodes was given by $2 + k \times (i + j)$. The number of side constraints using all the states was given by $j \times (i + 1) \times (k - 1) + i \times j$ which reduces to $j \times (i \times k + k - 1)$(side constraints=42). By eliminating the side constraints for the last state, this reduced to $j \times (i + 1) \times (k - 1)$(side constraints=30). For the case study, the number of side

constraints using the reduced model would become $12 \times (16+1) \times (3-1) = 408$ with the number of arcs being 661.

4.3 Network With Side Constraints - Multi-Commodity Flow

To try to reduce the number of side constraints, a second network with side constraints formulation was used that attempted to restrict flow to similar arcs or combinations of arcs within the various states. This second formulation resembled a multi-commodity flow network.

The source node was removed, as well as the arcs joining nodes 1, 2, and 3 to the source node. The inter-state arcs were also removed, thus effectively making all of the facility-location nodes (1 through 9) into source nodes. Additional arcs joining the sink node to these source nodes were generated for the SAS formulation, thus making the total number of arcs equal to 57, one less than in the previous formulation. The network now resembled three identical sub-networks all connected to the same sink as shown in Figure 4.3. The side constraints were such that if arc $x_{t,1}$ was chosen, arcs $x_{t,4}$ and $x_{t,7}$ would have to be chosen as well. This resulted in a total of six side constraints which looked promising(page L-2). However, as shown in Appendix L, all of the nine sink to source arcs were taken instead of only three. The resulting maximum cost flow was 295, vice the correct optimum of 284.

Additional side constraints were then added to the source-demand arcs to further restrict the flows to like paths(pages M-2, M-3). For example, if arc $x_{1,10}$ was taken, then arcs $x_{4,14}$ and $x_{7,17}$ must be taken as well (two extra equations). Overall, this resulted in a total of 30 side constraints as shown in Appendix M.

This formulation did not yield the desired one facility solution. The maximum cost flow was reduced to 289, but more than one of the state one facility-location nodes was chosen (2 and 3).

Even though this formulation did not provide the desired single site flow, an attempt was made to see if the number of side constraints could be reduced as had been done in Appendices J

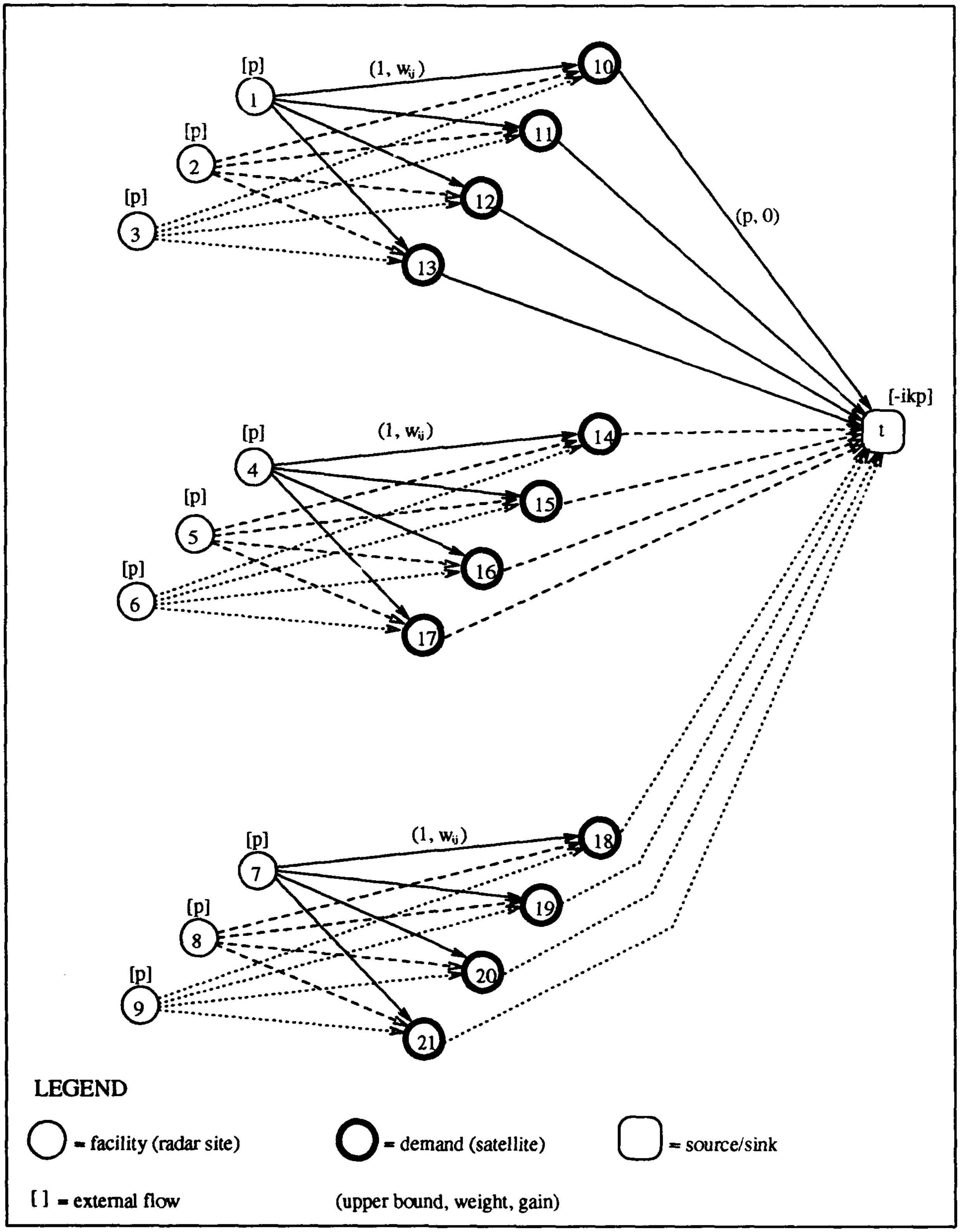

Figure 4.3. Multi-Commodity Flow Network

and K. Eight side constraints were removed by removing the set of constraints for state three. The results, shown in Appendix N, were identical to that obtained in Appendix M. Thus if a few more (less than eight) side constraints could be found to force the proper flow, this formulation would be more efficient than the previous network with side constraints (NWSC) modelling a network with gains.

At this point, the multi-commodity flow formulation (figure 4.3) contained two more arcs than the network with gains formulation (figure 4.2). The number of nodes had been decreased by one.

This network was further modified by adding a super-source to the first state of facilities as shown in figure 4.4. The net number of arcs and nodes were each increased by one from figure 4.3. Additional side constraints were added to try to force only one facility selection per state. For examp' ', these constraints were such that the total of flow along differing arcs emanating from different nodes within state one, when multiplied by the number of satellites in that state, [3] was less than or equal to the total flow from t to s. Thus one equation would be:

$$4x_{1,10} + 4x_{2,11} + 4x_{3,12} - x_{t,s} \leq 0 \tag{4.14}$$

Because there were more satellite than facility nodes per state (4 vs. 3), only three variables, other than $x_{t,s}$ could be included in the equation. Adding another variable such as $4x_{3,13}$ could force that variable and $x_{3,12}$ to be zero. Flow along $x_{t,s}$ was 4 and from previous solutions we know that the optimum was achieved by using site 3. By using $x_{3,12} = 1$ and $x_{3,13} = 1$ we would have $(4 \times 0) + (4 \times 0) + (4 \times 1) + (4 \times 1) - 4 \leq 0$ which is not valid mathematically, and would force one or both of the variables from one to zero in order to keep the equation feasible. Thus site 3 would incorrectly be rejected. This led to a requirement to add more constraints by varying the variables used in this 'arc-restriction' arrangement. The successful (integer result, single site

[3] The flow out is multiplied by the flow in so that when the equation is summed, the solution will be zero.

chosen) formulation and results are shown in Appendix O. In this formulation, sets of equations for all three states were used which resulted in 34 side constraints.

The set of equations for the third state were removed from the formulation in Appendix P in an attempt to reduce the number of side constraints (side constraints = 26). The solution was similar to the full formulation. A second reduction (Appendix Q) resulted in an undesirable integer solution with more than one facility chosen.

Analysis shows that not all of the possible 'arc-restriction' side constraints were listed. A fortunate choice of combinations of arc restricting constraints was sufficient to choose the correct optimal solution. The total number of arc restricting constraints should be given by

$$\frac{|J|!}{(|I|-|J|)!} \tag{4.15}$$

which in this case is 24 constraints. One can see that in this case 24 constraints (if none of the other constraints were used) is better than the 26 constraints used, but when the number of satellites in increased, even by one, the number of arc restricting constraints can rapidly escalate. For the case study this number would be $871,782,912,000$ which would be impractical to code. Thus it is imperative that a fortunate combination of arc restricting constraints and 'if flow in state x then also in state $x+1$, $x+2$, etc' constraints be found that could yield a solution for a large network.

As an aside, it should be noted that by reducing the number of facilities being evaluated, the number of arc restricting side constraints is reduced also. There is no difference in the number of arc restricting side constraints when $|J| = |I|$ or when $|J| = |I| - 1$.

4.4 *Summary for $p = 1$*

The generalized network did not generate an integer solution because it lost total unimodularity with the introduction of gains. The modified NWSC using implied gains was successful

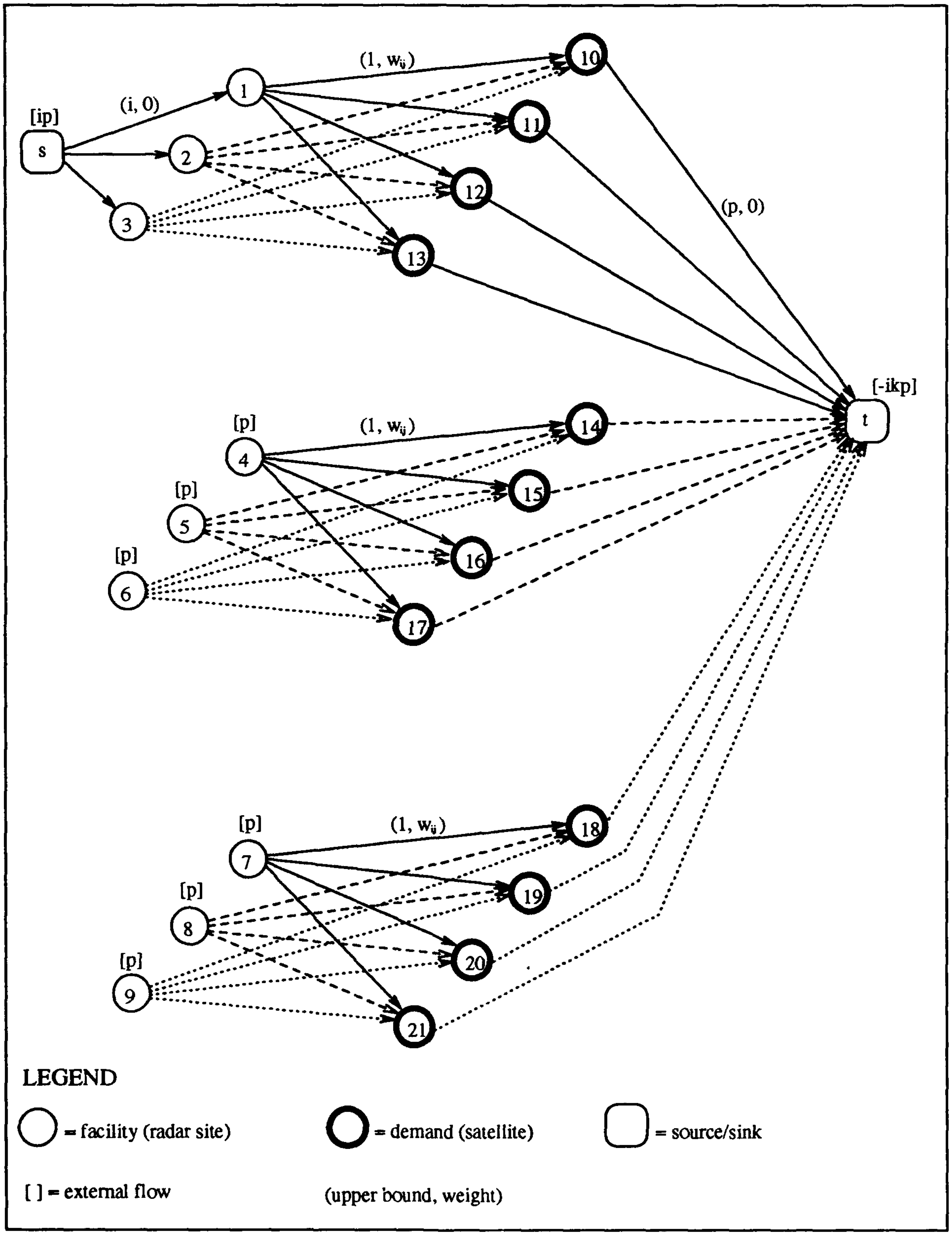

Figure 4.4. Multi-Commodity Flow Network With Super-Source

but used thirty side constraints compared to its 58 arcs and 38 nodes. The 'arc-restricting' multi-commodity flow NWSC had 26 side constraints for its 58 arcs and 38 nodes, however, the number of possible side constraints can increase drastically as the number of demands and facilities increase. For the $p = 1$ formulation, a simple enumeration of the total number of imagings per site is more computationally efficient than the network formulations, but a comparison must be made between facility totals as to the best one since the answer in the enumeration case is not a simple yes or no (1 or 0) as to facility selection.

For the $p = 1$ case for the 'test' problem, the optimal solution is 284 imagings using facility site three.

4.5 Selecting Two Sites ($p = 2$)

4.5.1 Network With Side Constraints Using Implied Gains Formulation. The reduced model (state three constraints removed) from Appendix J was modified for $p = 2$. The only change was to increase the arc capacities from one to two for the demand node to sink arcs (17 lines of code changed). The resulting formulation and solution is shown in Appendix S. The solution is the same as for the MIP83 run, 562 imagings.

4.5.2 Network With Side Constraints Using Multi-Commodity Flow Formulation. The reduced model from Appendix P was modified to account for $p = 2$ facilities to be chosen. As in the preceding $p = 2$ NWSC formulation, the demand nodes to sink arc capacities were changed from one to two. The arc restricting constraints remained at ≤ 0. Since the flow from t to s had doubled, the arc restricting constraints would still hold even if two of the arcs included in a single equation had flow through them. The resulting formulation and solution are shown in Appendix T. Again, the optimal answer agrees with the MIP83 solution.

The additional side constraints at the end of the problem that forced flow along identical arcs were removed and the 'arc-restricting' constraints increased to the maximum to try to improve the

node-arc incidence matrix to side constraint ratio, but a non-integer solution was obtained. The formulation in Appendix T was thus used for the case study.

4.5.3 Summary for $p = 2$. Both the NWSC using implied gains and the NWSC using multi-commodity flow formulations were successful. Even though the multi-commodity problem was smaller in this 'test' problem, it presented the possibility of becoming untenable as the number of facilities and demands increased. Both formulations were used in the case study.

V. Case Study

Once the methodology was selected, a 'real' world case was selected. The object was to maximize the number of satellites imaged choosing $p = 1, 2$ or 3 imaging radar sites. A total of 48 satellites was used with 16 satellites being assigned per state (31 day period). Twelve candidate locations were selected and evaluated. The procedure employed for the case study is graphically depicted in Figure 5.1.

5.1 The Set of Candidate Locations

The number of candidate locations for this example was limited to twelve sites which are listed in table 5.1 along with their geodetic location and elevation data. This data was used by the PASSCHED and MathCAD programs in calculating the number of observations. The twelve sites were chosen to represent a wide range of geographical locations while still maintaining the criteria that NDHQ/DAR had given.

Table 5.1. CANADA.OBS: Site Location Data

Site Location	*Latitude*	*Longitude*	*Height MSL (m)*
Alert NWT	82 31 00 N	062 17 00 W	30
Bagotville Que	48 19 50 N	070 59 47 W	159
Churchill Man	58 44 13 N	094 03 26 W	29
Cold Lake Alta	54 26 00 N	110 10 54 W	572
Gander Nfld	48 56 24 N	054 34 10 W	151
Gypsumville Man	51 45 36 N	098 37 54 W	260
Holberg BC	49 22 00 N	127 20 00 W	914
Moose Jaw Sask	50 19 48 N	105 33 32 W	577
North Bay Ont	46 21 49 N	079 25 23 W	370
St. Margarets NB	46 53 58 N	065 12 37 W	24
Whitehorse YT	60 42 37 N	135 03 59 W	703
Yellowknife NWT	62 27 45 N	114 26 20 W	206

This case study has assumed that the candidate locations have met the necessary political and economic criteria commonly used in selecting new installations. The decision maker can decide if these sites are acceptable, or can easily substitute different sites. There may be other essential

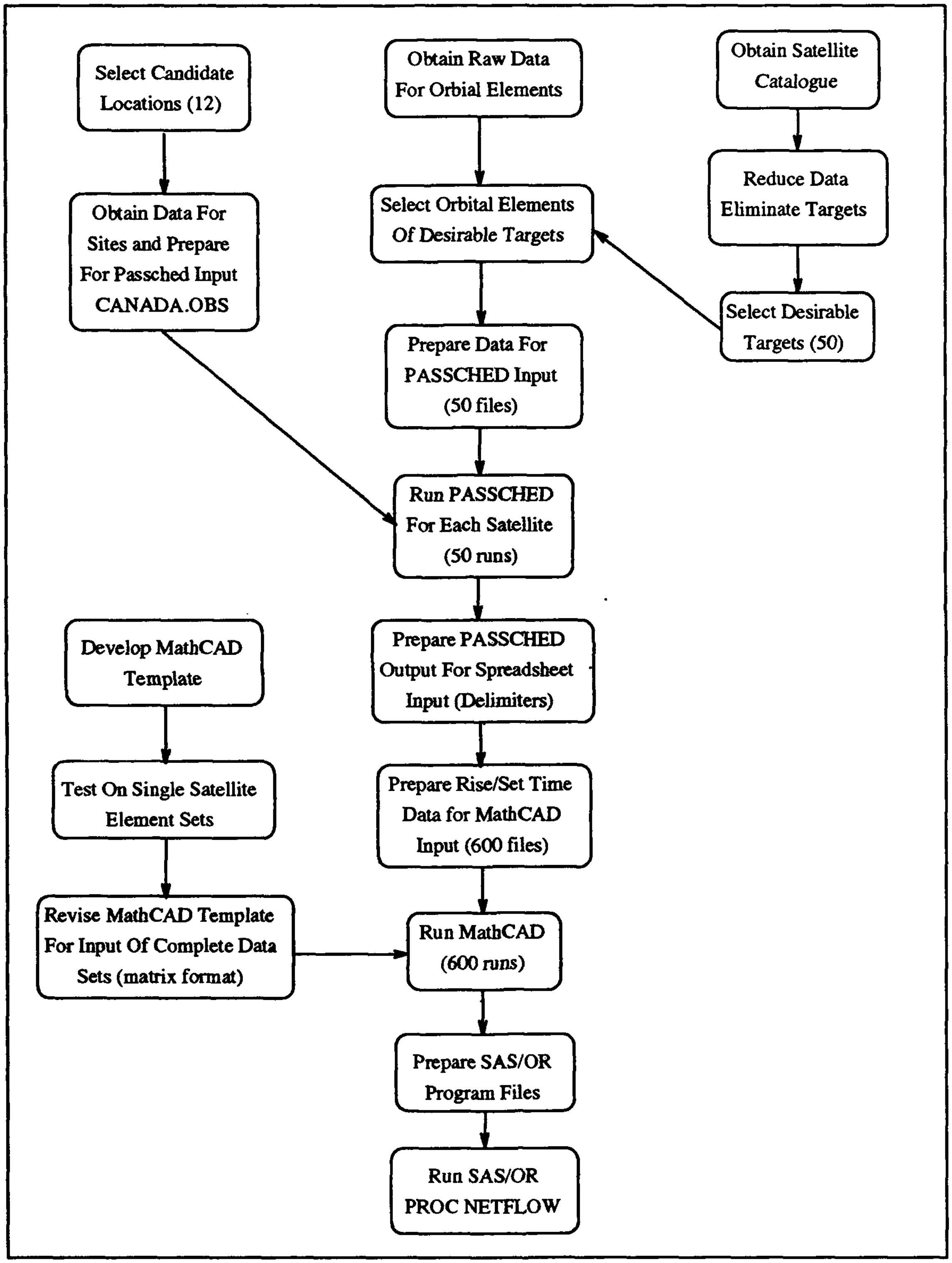

Figure 5.1. Case Study Procedure and Methodology

criteria that should be considered in the selection of the sites, but as a result of interviews with the decision maker(15), the selection was primarily based upon the more imagings, the better.

5.2 Choosing a Representative Satellite Population

Determining a representative satellite population was a difficult process because information was classified (security) as to the desired types and orbits of satellites that are desired targets. Thus, it was assumed that most desired targets are probably of the reconnaissance class and would require orbits that pass directly over Canada and the United States. One can assume that a majority of these satellites occupy a sun-synchronous type of orbit that would place the satellite over the same spot of North America at the same time every day. This is required to ensure that changes noted by the onboard optical instruments are changes due to man and not due to differing sun angles. Thus, out of the fifty satellites initially chosen, 24 satellites occupied orbits with inclinations from 90 to 99 degrees. The remainder of the satellites were chosen to provide a variety of orbital parameters (period, eccentricity, etc) with inclinations ranging from 43 degrees to 90 degrees. The satellites were selected through an elimination process from the NORAD satellite catalogue. Out of approximately 22,000 entries (3 megabytes on disk), the list was pared down by eliminating debris, rocket boosters, inclinations less than forty degrees, non-earth centred orbits, and orbits for which no element sets were listed. Fifty satellites were selected based upon the assumptions above, and the corresponding element sets were gathered from a relatively small (4.5 megabytes) file of NORAD two-line orbital element sets from July/August 1990. Only 48 satellites were required for the case study, but two extra were chosen to provide a backup should one of the orbits be unusable[1]. The satellites chosen and the applicable parameters from the NORAD

[1] This was the case with the Soviet Granat satellite which, although it was within view of all of the sites many times during the 31 day period, was not imaged by the majority of sites. Its orbit was quite different from the other satellites (0.9 eccentricity) and probably did not fit the category of a 'spy' satellite, but was initially chosen for its differences. Unusable meant that inclusion of that satellite in the problem would be too restrictive for a test of the procedures used in this research.

two-line element sets are shown in Appendix U. This data was used in both the PASSCHED[2] and MathCAD programs.

5.3 PASSCHED Calculations

After gathering the NORAD two-line element sets for the fifty chosen satellites, the data was prepared for PASSCHED[3] input. The pass scheduler is a program that generates rise and set times of satellite passes from a set pre-selected files of observation sites and NORAD two-line orbital element sets. The purpose of using this program was to generate pairs of rise and set times for observations from each of the radar sites such that the MathCAD program could determine if the satellite had been imaged. The site data was placed in a file called CANADA.OBS (Table 5.1 which contained the name of the site, the latitude and longitude of the site using the qualifiers N and W for the directions as applicable, and the height of the site in metres above mean sea level (MSL). For ease of handling, the fifty satellites with their two-line element sets were broken down into smaller files which basically described their inclination: ORBIT40.TLE, ORBIT50.TLE, ORBIT60.TLE, ORBIT70.TLE, OBRIT80.TLE, ORBIT90A.TLE, ORBIT90B.TLE, and ORBIT90C.TLE. The PASSCHED program was run fifty times choosing one satellite at a time. For all runs, the minimum rise angle required for inclusion in the output, and the mask angle were set at five degrees[4]; the minimum observation time was set to zero minutes; and the start and finish times were set to 0000 hrs GMT[5] 1 Sep 90 and 0000 hrs GMT 1 Oct 90, respectively. The fifty output files totalled approximately nine megabytes of information. An example of an output file is shown in Appendix A.

The PASSCHED output was designed for human interpretation and was not suitable for MathCAD input since the dates were only included for the first pass of each day. Occasionally a satellite would rise late on one day and set early on the next day. Since only one date, if any, was

[2] The full two-line element set was used in the PASSCHED program.
[3] PASSCHED (Pass Scheduler)(18) was written by Dr T.S. Kelso at AFIT, WPAFB.
[4] Bohannon and Young(5:3) state that at elevations below five degrees above the horizon, atmospheric attenuation reduces the sensitivity of the Haystack radar.
[5] Greenwich Mean Time or Universal Time.

on an output line, the user was left to interpret the difference in dates by the numerical values of the times: a set time of lesser value than the rise time meant a new day.

The PASSCHED output data was prepared for spreadsheet input by deleting control characters in the file and delimiting the columns of data using a word processor and macros. MicroSoft Excel was used to convert the date and time entries into a Julian day for the year 1990. If no date was present on that line, the spreadsheet was instructed to assume the previously given date. The formulas also compared rise and set times so that the appropriate Julian day was assigned to the set times. The resulting fifty intermediate step Excel files took up 45 megabytes of disk space. The Excel files were then broken down into one site per satellite from the twelve sites per satellite files. The resulting 592[6] two column files were saved in ASCII format with a preceding letter in the file name to describe the site/satellite combination: E.g. D6CS1884.PRN for the rise/set time of COSMOS 1884 as viewed by Cold Lake, Alberta. The files contained two columns which described rise and set time pairs in JD.HHMMSS format; E.g. 144.154308, Julian Day 244 (2 Sep), 15 hours, 43 minutes, and 8 seconds. A sample of the input format is shown in Appendix A and a small sample of the final output format is shown in table 5.2. The final result was 592 files (three megabytes) suitable for MathCAD input[7].

5.4 MathCAD Program

The MathCAD program was designed to take the modified PASSCHED rise/set times and calculate an effective angle of rotation that the satellite had rotated through with respect to the observing radar. It was assumed that the largest angle of rotation occurs between the first sighting and the last sighting by the radar. The coordinate transformations and calculations are documented with the MathCAD program listed in Appendix B.

[6] Eight satellite/site combinations contained no observations.

[7] There should have been 600 files except that there eight cases where zero observations were recorded.

Table 5.2. Rise/Set Times: Input for MathCAD

Rise Time JD.HMS	*Set Time JD.HMS*
244.080739	244.081800
244.094550	244.095743
244.112523	244.113317
244.192133	244.192859
244.205632	244.210845
244.223543	244.224706
245.070951	245.071547
245.084646	245.085825
245.102530	245.103621
245.195848	245.200913
245.213545	245.214814
245.231652	245.232556
246.074810	246.075747
⋮	⋮
273.183838	273.184916
273.201652	273.202753
273.220043	273.220351

The weights, or number of observations was determined by calculating the number of times in a one month period that a satellite could be imaged by a radar site. The 'observation' depended upon several orbital and radar limitations. For a given desired cross-range resolution (say 0.12 metres), an imaging radar must 'observe' the satellite through a minimum angular rotation given by the following equation(21:23):

$$\Delta = \frac{\lambda}{2\sin\Theta} \tag{5.1}$$

where:

Δ is the desired cross-range resolution.

λ is the wavelength of the radar in metres, and can be calculated by dividing the propagation speed (essentially the speed of light) by the frequency of the radar (12 GHz).

Θ is the apparent angular rotation of the satellite as viewed by the beam of radar.

To determine if a satellite was observed for the minimum angular rotation, the GCI coordinates of the radar were determined for the times when the satellite was ascending and descending through 5 degrees above the horizon (the limit of radar field of view). The satellite's ECI coordinates and the radar's ECI coordinates were transformed using a rotation matrix into the coordinate frame of the satellite. The radius vector, in the satellite coordinate frame, from the radar site to the satellite was calculated for the rise and fall times of the satellite, and then by performing a dot product of these two radius vectors, an angular rotation for the satellite was determined. If this angular rotation was greater than the minimum determined by equation 5.1, then an observation was recorded.

An additional coordinate transformation was performed to place the satellite in the coordinate frame of the radar. This gave azimuth and elevation information which was checked against the PASSCHED output to confirm that the same calculations and assumptions had been performed on the orbital element sets and thus the times were safe to use. The calculations were confirmed.

The MathCAD program was run 592 times, once for each of the satellite/site combinations[8]. During the runs, appropriate changes were made to the program to ensure that the correct site data and element set were read in to correspond with the .PRN file being calculated. The output, including the null sets, resulted in 600 numbers which described the number of times that each of the twelve radars had imaged the fifty satellites in a 31 day period. This data[9] was used for the costs/weights in the objective function of the SAS/OR program files.

5.5 SAS/OR Program Files

Based upon the success of the two NWSC formulations developed in the preceding chapter, SAS/OR program files were prepared for the site ($j = 12$) and satellite ($i = 16$, $k = 3$) data. The input files were modelled after the reduced formulations presented in Appendices J and P. The

[8]Eight of the 600 possible combinations were null sets and were not run.
[9]Minus two satellites

variables describing the site-satellite arcs were named using a letter from A to L and a number from one to three to describe the site and which state it was in, and a number from 01 to 48 to describe the satellite. The 48 satellites were randomly placed into three sets of 16 satellites representing the three states. This simplistic model assumed that the decision maker would be aiming to image the first 16 satellites this month, the second 16 satellites next month, etc.

As discussed previously, the number of constraints escalates rapidly as the number of demands and sources increase. The resulting SAS/OR program files were too large (> 500 kilobytes each) to be included in their entirety as an Appendix. The final program files are stored on $3\frac{1}{2}$ inch high density diskettes with the Department of Operational Sciences at AFIT, Wright-Patterson AFB, Ohio.

5.6 *Results and Analysis*

5.6.1 Network With Side Constraints Using Simulated Gains. A partial listing of the program for $p = 1$ is shown in Appendix V. As calculated in the previous chapter, the number of side constraints was 408. Unfortunately, for this formulation, with the number of side constraints, variables, and calculations required, the computations were halted due to errors stated by SAS as:

> ERROR: Working basis matrix singular in iteration 250. The problem may be numerically unstable. ZERO2 may need altering. Try rerunning using different pricing strategies etc. that may avoid this basis.
>
> NOTE: Will assume that the successive column updates have accumulated round-off errors. The working basis matrix will be refactorized.

When the program was modified for $p = 2$, the SAS program halted after 298 iterations. These errors could possibly be due to computer round off error due to the number of matrix inversions involved in these calculations. This formulation may work for other numbers or smaller formulations, as it did in the 'test' problem, but it did not work for this combination of costs and variables.

5.6.2 Network With Side Constraints Using Multi-Commodity Flow. A partial listing of this formulation for $p = 1$ is shown in Appendix W. As discussed in the previous chapter, this formulation is of a factorial nature with respect to the total number of 'arc-restricting' side constraints possible. But, also based upon the success of the 'test' problem in using less than the maximum number of arc restricting side constraints, an attempt was made to solve the case study for 1, 2, and 3 facilities. Initially the $p = 1$ problem was formulated with five arc restricting side constraints such that all of the satellites in state one were included in the five equations:

$$x_{a1,1} + x_{b1,2} + x_{c1,3} + x_{d1,4} + x_{e1,5} + x_{f1,6} + x_{g1,7} + \ldots + x_{k1,11} + x_{l1,12} \leq 0$$

$$x_{a1,1} + x_{b1,3} + x_{c1,4} + x_{d1,5} + x_{e1,6} + x_{f1,7} + x_{g1,8} + \ldots + x_{k1,12} + x_{l1,13} \leq 0$$

$$x_{a1,1} + x_{b1,4} + x_{c1,5} + x_{d1,6} + x_{e1,7} + x_{f1,8} + x_{g1,9} + \ldots + x_{k1,13} + x_{l1,14} \leq 0$$

$$x_{a1,1} + x_{b1,5} + x_{c1,6} + x_{d1,7} + x_{e1,8} + x_{f1,9} + x_{g1,10} + \ldots + x_{k1,14} + x_{l1,15} \leq 0$$

$$x_{a1,1} + x_{b1,6} + x_{c1,7} + x_{d1,8} + x_{e1,9} + x_{f1,10} + x_{g1,11} + \ldots + x_{k1,15} + x_{l1,16} \leq 0$$

Additionally, there were 24 side constraints $(j \times (k-1))$ to ensure that if a super source–facility arc in state one was chosen, the corresponding arcs in states two and three would also have the same flow. There were also 384 side constraints $(i \times j \times (k-1))$ that ensured that if a facility–demand arc in state one was chosen, the corresponding arcs in states two and three were also selected.

The set of arc restricting side constraints was obviously not all inclusive, but it did provide a starting point whereby an integer solution was given. This solution chose facility C as filling 12 demands, while facilities F and G each filled one demand, and facility J filled two demands. The solution given was 10299 imagings which was higher than the eventual optimal solution because more than one site had been chosen. Two additional arc restricting side constraint equations were

inserted such that the demands that F, G, and J had filled were included in an equation along with a demand that C had filled. Thus this would force the next solution to choose only one of the above facility–demand flows. The facilities that had not been selected were also inserted into the equations such that there was no repetition of satellites within the same equation. For example, the following equations were used (the critical variables are highlighted):

$$x_{a1,5} + x_{b1,6} + \boldsymbol{x_{c1,7}} + x_{d1,8} + x_{e1,9} + \boldsymbol{x_{f1,4}} + \boldsymbol{x_{g1,3}} + x_{h1,12} + \boldsymbol{x_{i1,1}} + x_{j1,14} + x_{k1,15} + x_{l1,16} \leq 0$$

$$x_{a1,5} + x_{b1,6} + \boldsymbol{x_{c1,7}} + x_{d1,8} + x_{e1,9} + x_{f1,10} + x_{g1,11} + x_{h1,12} + \boldsymbol{x_{i1,2}} + x_{j1,14} + x_{k1,15} + x_{l1,16} \leq 0$$

The next solution with the new constraints added chose facilities B, E, G, and H as well as C, with a solution of 10270 imagings. The facilities B, E, G, and H had only imaged one satellite in each state, and thus only one extra constraint was required for the next formulation:

$$x_{a1,5} + \boldsymbol{x_{b1,1}} + x_{c1,7} + x_{d1,8} + \boldsymbol{x_{e1,2}} + x_{f1,10} + \boldsymbol{x_{g1,x4}} + \boldsymbol{x_{h1,3}} + x_{i1,13} + x_{j1,14} + x_{k1,15} + x_{l1,16} \leq 0$$

This procedure was repeated five times until a non-integer solution was given. Even though the values given for the arcs were now non-integer, this facility-demand elimination procedure could still be applied. The number of constraints added, however, was usually more per iteration than for the integer solutions, since more than one facility was imaging a single satellite[10]. The effect of the iterations upon the optimal solution is shown in Figure 5.2.

In an attempt to come to the feasible (only one site chosen) optimal solution quicker, the equi-distribution of flow constraints (equation 4.3) were added for the facility nodes. This resulted in an additional 192 side constraints. The new equations were given as:

$$16x_{a1,1} - x_{s,a1} = 0$$

[10]The sum for each satellite was still one.

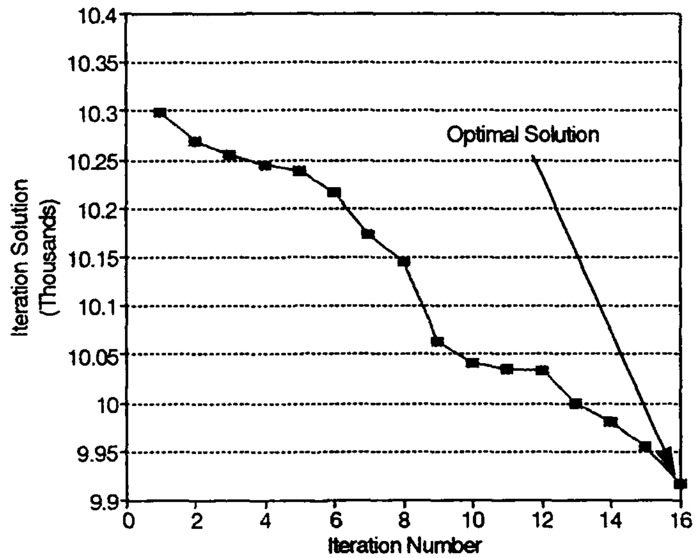

Figure 5.2. Iterative Solutions For $p = 1$ Using Multi-Commodity Flow Formulation

$$16x_{a1,2} - x_{s,a1} = 0$$

$$\vdots$$

$$16x_{a1,16} - x_{s,a1} = 0$$

$$16x_{b1,1} - x_{s,b1} = 0$$

$$\vdots$$

$$16x_{l1,15} - x_{s,l1} = 0$$

$$16x_{l1,16} - x_{s,l1} = 0$$

These constraints forced flow along all 16 arcs emanating from a facility, if there was flow into that facility. The factor of 16 was used in the constraints since any flow into the facility must be 16 to ensure a flow of one out of the sixteen arcs leaving the facility.

However, when the new formulation was run, at iteration 1172, a singular matrix was encountered and SAS warned of a round off error similar to the error encountered when testing the NWSC using simulated gains. It was reasoned that since there appeared to be a trend towards facility C, the equi-distribution of flow for the remaining fifteen facilities could be dropped and perhaps solve the singular matrix problem. If the trend toward facility C was false, then the inclusion of the singular set of equi-distribution of flow equations would force C out of the solution. The resulting run proved successful with the optimal solution being 9917 imagings using site C (Churchill, Manitoba). The solution is shown at Appendix W. This solution corresponded with the solution given when an enumeration of all of the site-satellite pairs was performed.

Based upon this success, the initial formulation using only five arc restricting side constraints was reconfigured to include the 16 equi-distribution of flow constraints for facility C. This formulation was also successful (only one site chosen) and showed that, in this case, once a pattern had developed, the equi-distribution of flow side constraints could be used to quicken the arrival of a solution.

To confirm that the equi-distribution of flow constraints would either force the integer solution, or kick the facility out of the solution set, fifteen additional runs were made using the formulation in the preceding paragraph, and modifying the 16 equi-distribution of flow constraints to include the other facilities, one at a time. None of these other formulations resulted in a wholely integer solution. However, the facility that had been included in the equi-distribution of flow constraints did not appear in the solution set, thus confirming the assumption above.

The NWSC using multi-commodity flow was run again for $p = 2$ and $p = 3$ facilities to be chosen. The formulations were identical to the $p = 1$ formulation with the only changes being

the limit of the upper bound for the 48 demand-sink arcs. The upper limits corresponded to he number of facilities to be chosen. The output from the SAS/OR runs are shown in Appendix W. The results of these two sets of runs were similar to the $p = 1$ calculations. A summary of the sites chosen is shown in Table 5.3.

Table 5.3. Sites Chosen By NWSC

p	Location(s) Chosen
1	Churchill, Manitoba
2	Churchill, Manitoba Whitehorse, Yukon Territory
3	Churchill, Manitoba Whitehorse, Yukon Territory Alert, North West Territories

The trend appears to favour northern sites which had more imagings of the high inclination satellites. Recall that the high inclination satellites comprised the plurality of the satellites in this case study. Churchill is chosen first since it is the most northerly site that can still image all of the candidate satellites. Once that constraint is met, the network flows chooses the sites with the most number of imagings.

VI. Conclusions and Recommendations

6.1 Summary

This research has presented a study of the maximal coverage p-median facility location problem as applied to the imaging radar facility location problem. The classical mathematical formulation of the maximal coverage problem was converted into network-flow with side constraint formulations which had been developed using a small 'test' problem.

Although both the network with side constraints (NWSC) using simulated gains, and the NWSC using multi-commodity flow had worked for the 'test' problem for $p = 1$ and $p = 2$ facilities to be chosen, the formulations ran into difficulties with the large scale case study. These difficulties were largely the result of the VAX's computational round off errors introduced during the matrix inversion process.

In the case study, the NWSC using multi-commodity flow resulted in solutions that appeared to show a trend towards an optimal solution. An iterative process was adopted using results from each run to eliminate the facility-demand arc flows for the facilities that imaged only a few satellites. This process eventually went from integer to non-integer solutions, however, the trend towards an optimal solution continued. The addition of equi-distribution of flow constraints for those facilities that appeared to be the facilities to be chosen resulted in an immediate optimal solution. Although the multi-commodity flow formulation for this case study could have a possible $871,782,912,000$ arc restricting side constraints, when combined with a selected set of equi-distribution of flow side constraints, a solution has been achieved in as little as two steps, and with as few as five of the arc restricting constraints included[1].

Using a selected group of satellites and the candidates sites shown in Table 5.1, a set of sites shown in Table 5.3 was chosen for $p = 1$, $p = 2$, and $p = 3$ sites. The selected sites tended to be

[1]The 'if state i, then state $i + 1, 2,$ etc.' and like arcs in different states constraints described in Chapters IV and V were still required in the formulation; their requirement never changed.

located at northerly latitudes where more observations of the high inclination satellites occurred. Because of the secretive classification of the desired targets, the results of this research are only an illustration of the selection of potential facility sites. The solution methodology used in this research is receptive to changes in site locations and numbers of sites and satellites. The end user of this methodology will have a more accurate knowledge of target satellites and imaging requirements for input than this research had, and thus will be able to accurately choose a site.

Two formulations of networks with side constraints provided results. However, the NWSC using simulated gains appeared to be susceptible to computational round off error as a result of matrix inversions, possibly due to the highly organized nature of the side constraints.

Modelling the problem with a multi-commodity type network initially appeared to be impractical due to the potential factorial nature of the number of arc restricting side constraints required. However, with the addition of some equi-distribution of flow constraints, this formulation can be solved in as little as two steps. The first step would involve using the formulation with a minimal number of arc restricting constraints, covering all the demands from at least one facility, which would supply a solution that may indicate a trend. That trend would be used to develop a set of equi-distribution of flow side constraints for the indicated facility or facilities, and these constraints included in the second step of the NWSC procedure. The equi-distribution of flow constraints would either prove or reject the given trend. If the trend was rejected (the indicator for that facility now being zero), a new trend would appear and another set of equi-distribution of flow side constraints would be added.

It should be noted that there are other methods, such as the knapsack problem, that can be as efficient, or more so than NWSC. However, the NWSC method was evaluated since it can be easily modified to include additional constraints, or be converted to a set covering type of problem, or be used for multi-criteria problems.

6.2 Recommendations For Further Study

The imaging radar location problem is formulated and solved by applying the concepts and theories of three distinct areas: astrophysics, radar, and operations research. The solution methodology developed in this paper could be improved by further work in any of these disciplines.

A major assumption made in the development of this methodology is that networks with side constraints are more computationally efficient than standard linear and integer programming methods. Although for the $p = 1$ problem, straight enumeration may be as effective as the NWSC calculations, increasing the number of facilities to be chosen should favour the NWSC methodology. It remains to be shown, however, that when the number of side constraints approach or exceed the number of items in the node-arc incidence matrix, that the NWSC methods developed here are still more computationally efficient than linear programming procedures.

A sensitivity analysis of this solution methodology for the solution with respect to the input parameters should be performed. A procedure needs to be developed which would determine the effects of varying site/satellite/state parameters, numbers, and combinations.

The NWSC using simulated gains shows potential as a consistent formulation for any number of p. However, a method needs to be developed which would break down the highly organized side constraint matrix into smaller combinations of identical matrices, and use this to avoid the current singular matrix error which results after a number of matrix inversions and resulting computational round off error. Unless a method can be found to bypass this error by taking advantage of this organization, this formulation does not appear to work for large problems. An advantage to this formulation, should a method be devised to bypass the matrix singularity problem, is that the same formulation works for all values of p, with the only changes required being in the upper limits of the demand-sink arcs to correspond to the value of p.

The effects of varying bandwidth and frequency of the imaging radar within the same formulation, or by using a series of formulations with different radar parameters, should be explored

to determine the impact upon a choice of sites. The MathCAD program and NWSC formulations used in this research are presently set up for only one set of imaging radar characteristics at a time.

The methods used in going from the pass scheduling program (PASSCHED) to the SAS/OR program were very labour intensive. The PASSCHED program could be modified to perform the calculations necessary to determine the number of imagings per site for each satellite, and convert these into the required SAS/OR input files. An additional program could be developed to take the first run NWSC multi-commodity flow output, and based upon the first run trends, calculate the necessary equi-distribution of flow constraints required, or additional arc restricting constraints required (if any), for the second step of the procedure. This research could also be used to determine if this method will consistently lead to an optimal solution.

The similarity of the curve shown in Figure 5.2 to that shown in Chan(7) and Nemhauser(23) with respect to Benders' Decomposition indicates that it may be possible to predict an optimal solution based upon a trend towards a given site. Further research should be conducted to confirm that a relationship exists.

Appendix A. *Sample of PASSCHED Output*

Observing Site:	Cold Lake Alta	Start time:	01/0000 Sep 1990
	54 26 00 N	Stop time:	01/0000 Oct 1990
	110 10 54 W	Min elevation:	5 degrees
	572 meters AMSL	Mask angle:	5 degrees

Satellite	Date	Rise	Az	El	ToC	Az	El	Set	Az	El	Vis
N 1	01 Sep 1990	080739	15	5	081256	74	22	081800	134	5	
N 1		094550	358	5	095156	276	66	095743	194	5	
N 1		112523	339	5	112923	297	13	113317	256	5	
N 1		192133	98	5	192516	61	11	192859	24	5	
N 1		205632	160	5	210236	82	54	210845	4	5	
N 1		223543	216	5	224122	282	29	224706	348	5	
N 1	02 Sep 1990	070951	32	5	071251	62	8	071547	92	5	
N 1		084646	7	5	085245	84	46	085825	161	5	
N 1		102530	351	5	103103	286	30	103621	219	5	
N 1		195848	127	5	200400	70	22	200913	13	5	
N 1		213545	184	5	214157	271	73	214814	357	5	
N 1		231652	245	5	232123	292	14	232556	339	5	
N 1	03 Sep 1990	074810	17	5	075304	72	18	075747	126	5	
N 1		092609	0	5	093215	274	81	093801	187	5	
N 1		110529	342	5	110953	295	15	111408	248	5	
N 1		190243	89	5	190548	58	9	190853	28	5	
N 1		203701	153	5	204300	79	44	204900	6	5	
N 1		221543	209	5	222135	280	35	222730	350	5	
N 1		235958	285	5	000143	302	6	000328	318	5	
N 1	04 Sep 1990	065100	40	5	065252	59	6	065442	77	5	
N 1		082710	9	5	083258	81	37	083827	154	5	
N 1		100545	353	5	101127	283	37	101652	213	5	
N 1		114628	324	5	114827	305	7	115024	285	5	
N 1		193934	120	5	194428	68	18	194922	16	5	
N 1		211602	177	5	212216	268	88	212832	359	5	
N 1		225635	236	5	230130	289	17	230626	342	5	
N 1	05 Sep 1990	072843	21	5	073310	69	15	073728	117	5	
N 1		090629	2	5	091233	91	82	091816	180	5	
N 1		104538	344	5	105021	292	18	105453	240	5	
N 1		184408	77	5	184621	56	7	184835	35	5	
		.									
		.									
		.									
		.									
		.									
N 1	31 Sep 1990	231811	260	5	232146	296	10	232521	332	5	

Appendix B. *MathCAD Template For Calculating Number Of Imagings*

MathCAD Program for Calculating Number of Radar Observations

Definition of constants used in calculations

$\omega_e := 1.00273790934 \cdot \frac{rev}{day}$ revolutions of the earth per mean solar day (24 hours)

$R_e := 6378.140 \cdot km$ Earth's equatorial radius

$\mu := 3.986005 \cdot 10^{14} \cdot \frac{m^3}{sec^2}$ Geocentric gravitational constant

$f := \frac{1}{298.257}$ Flattening factor for the Earth

$J_2 := 0.00108263$ First Order Secular Variation due to Earth's gravity

1. Calculate Geocentric Latitude of the Observing Site

sitedata := READPRN(canada) Site location data for all twelve selected sites

colns := cols(sitedata) colns = 7 number of columns of data

c := 1 ..colns

Example: pick out data for St. Margarets, N.B.

$OD_c := sitedata_{10,c}$ $OD^T = (46\ \ 53\ \ 58\ \ 65\ \ 12\ \ 37\ \ 24)$

where first three entries are Latitude in degrees, minutes, seconds North; next three entries are Longitude in degrees, minutes, seconds West; and final entry is height of site above Mean Sea Level in metres

$h := OD_7 \cdot m$ $h = 24 \cdot m$

Mean Anomoly at time of setting

$$M_{set_r} := \mathrm{mod}\left[M_o \cdot rad + n_o \cdot \left[t_{set_r} - EJD\right] + ndot_1 \cdot \left[t_{set_r} - EJD\right]^2, 2 \cdot \pi\right]$$

$M_{set_j} = 4.5894 \cdot rad$ $\quad$ $M_{set_j} = 262.956 \cdot deg$

$E := M + e \cdot \sin(E)$ ▫ $\quad$ Equation for Eccentric Anomoly which must be solved iteratively

$E_{ris_r} := M_{ris_r} + e \cdot \sin\left[M_{ris_r}\right]$ $\quad$ Initial estimate of Eccentric Anomoly at time of rise

$E_{ris_r} := \mathrm{root}\left[M_{ris_r} - E_{ris_r} + e \cdot \sin\left[E_{ris_r}\right], E_{ris_r}\right]$ ▫

$E_{set_r} := M_{set_r} + e \cdot \sin\left[M_{set_r}\right]$ $\quad$ Initial estimate of Eccentric Anomoly at time of setting

$E_{set_r} := \mathrm{root}\left[M_{set_r} - E_{set_r} + e \cdot \sin\left[E_{set_r}\right], E_{set_r}\right]$ ▫

$E_{ris_j} = 2.5195 \cdot rad$ $\quad$ $E_{set_j} = 4.5873 \cdot rad$

Convert Geodetic Latitude to decimal degrees format

$$\phi := \left[OD_1 + \frac{OD_2}{60} + \frac{OD_3}{3600}\right]\cdot deg$$

$\phi = 46.8994\cdot deg$

North Geodetic Latitude

Convert Longitude to decimal degrees format East of 0 degrees

$$\lambda_E := \left[360 - \left[OD_4 + \frac{OD_5}{60} + \frac{OD_6}{3600}\right]\right]\cdot deg$$

$\lambda_E = 294.7897\cdot deg$ East of the Prime Meridian

Convert Geodetic Latitude to Geocentric Latitude

$$\phi_{gc} := \left[atan\left[(1 - f)^2\cdot tan(\phi)\right]\right]$$

$\phi_{gc} = 46.7074\cdot deg$

(North, Geocentric Latitude)

2. Calculate Local Siderial Time at the Observing Site

A reference time is used in calculations of ECI coordinates. The reference time is GAST (Greenwich Apparent Siderial Time) which for 0 hrs UT 1 Sep 90 (Julian day number 244) is 22 hrs, 39 min, 35.9203 sec.

Convert date and time to decimal day format

$\theta_{go} := 22\cdot hr + 39\cdot min + 35.9203\cdot sec$ $\theta_{go} = 22.66\cdot hr$

Our Reference Julian Day (using 0 hrs UT 1 Jan 90 as 1.0) is:

$RJD := 244\cdot day$

θ_{go} defined in terms of radians is:

$$\theta_{go} := \frac{\theta_{go}}{24\cdot hr}\cdot 2\cdot \pi$$

$\theta_{go} = 5.9324\cdot rad$

$$\omega_o := \left|sat^{\langle 6\rangle}\right| \cdot deg$$

Argument of Perigee at Epoch

$\omega_o = 210.675 \cdot deg$ $\omega_o = 3.677 \cdot rad$

$$M_o := \left|sat^{\langle 7\rangle}\right| \cdot deg$$

Mean Anomaly at Epoch

$M_o = 149.2556 \cdot deg$ $M_o = 2.605 \cdot rad$

$$n_o := \left|sat^{\langle 8\rangle}\right| \cdot \frac{rev}{day}$$

Mean Motion (revolutions per solar day)

$$n_o = 2.13102429 \cdot \frac{rev}{day}$$

$$a := \left[\frac{\mu}{\left[n_o\right]^2}\right]^{\frac{1}{3}}$$

a is the length of the semi-major axis of the ellipse formed by the orbit

$a = 25507.9914 \cdot km$

$$p := a \cdot \left[1 - e^2\right]$$

$p = 25507.8715 \cdot km$

Application of the first order J_2 secular variations for:

Regression of the line-of-nodes

$$\Omega_{ris} := \Omega_o - \left[\frac{3 \cdot J_2 \cdot R_e^2}{2 \cdot a^2 \cdot \left[1 - e^2\right]^2}\right] \cdot \cos\left[i_o\right] \cdot n_o \cdot \left[t_{ris} - EJD\right]$$

$\Omega_{ris_j} = 0.6359 \cdot rad$ $\Omega_{ris_j} = 36.4369 \cdot deg$

$$\Omega_{set} := \Omega_o - \left[\frac{3 \cdot J_2 \cdot R_e^2}{2 \cdot a^2 \cdot \left[1 - e^2\right]^2}\right] \cdot \cos\left[i_o\right] \cdot n_o \cdot \left[t_{set} - EJD\right]$$

$\Omega_{set_j} = 0.6359 \cdot rad$ $\qquad$ $\Omega_{set_j} = 36.4318 \cdot deg$

Rotation of the line-of-apsides

$$\omega_{ris} := \omega_o + \left[\frac{3 \cdot n_o \cdot J_2 \cdot R_e^2}{a^2 \cdot \left[1 - e^2\right]^2}\right] \cdot \left[1 - \frac{5}{4} \cdot \sin\left[i_o\right]^2\right] \cdot \left[t_{ris} - EJD\right]$$

$\omega_{ris_j} = 3.6738 \cdot rad$ $\qquad$ $\omega_{ris_j} = 210.493 \cdot deg$

$$\omega_{set} := \omega_o + \left[\frac{3 \cdot n_o \cdot J_2 \cdot R_e^2}{a^2 \cdot \left[1 - e^2\right]^2}\right] \cdot \left[1 - \frac{5}{4} \cdot \sin\left[i_o\right]^2\right] \cdot \left[t_{set} - EJD\right]$$

$\omega_{set_j} = 3.6738 \cdot rad$ $\qquad$ $\omega_{set_j} = 210.4924 \cdot deg$

Mean Anomoly at time of rise

$$M_{ris_r} := \mathrm{mod}\left[M_o \cdot rad + n_o \cdot \left[t_{ris_r} - EJD\right] + ndot_1 \cdot \left[t_{ris_r} - EJD\right]^2, 2 \cdot \pi\right]$$

$M_{ris_j} = 2.5183 \cdot rad$ $\qquad$ $M_{ris_j} = 144.2854 \cdot deg$

$t_{ris_j} = 244.1789 \cdot day$ $\qquad$ $t_{set_j} = 244.3336 \cdot day$

The angle between the unit vector I (vernal equinox direction) and the Greenwich meridian is the greenwich siderial time, which for the rise and set time of the satellite are given by:

$$\theta ris_g := \theta_{go} + \left[t_{ris} - RJD\right] \cdot \omega_e \qquad \theta ris_{g_j} = 7.0593 \cdot rad$$

$$\theta set_g := \theta_{go} + \left[t_{set} - RJD\right] \cdot \omega_e \qquad \theta set_{g_j} = 8.0339 \cdot rad$$

The local siderial time for the observing site is given by:

$$\theta ris_r := mod\left[\theta ris_{g_r} + \lambda_E, 2 \cdot \pi\right] \qquad \theta ris_j = 5.9212 \cdot rad$$

$$\theta set_r := mod\left[\theta set_{g_r} + \lambda_E, 2 \cdot \pi\right] \qquad \theta ris_j = 5.9212 \cdot rad$$

3. Calculate ECI (Earth Centred Inertial) Coordinates of Observing Sites

Intermediate calculations using quasi-constants C and S:

$$C := \frac{1}{\sqrt{\cos(\phi)^2 + (1 - f)^2 \cdot \sin(\phi)^2}} \qquad C = 1.0018$$

$$S := (1 - f)^2 \cdot C \qquad S = 0.9951$$

Calculation of distance and radius vectors from centre of ECI coordinates to radar site:

$$R_o := R_e \cdot \sqrt{\frac{1}{2} \cdot \left[S^2 + C^2\right] + \frac{1}{2} \cdot \left[C^2 - S^2\right] \cdot \cos(2 \cdot \phi)}$$

scalar distance to a point at MSL approximately beneath the radar site

$R_o = 6366.7839 \cdot \mathrm{km}$

$h = 24 \cdot \mathrm{m}$ altitude of radar site above MSL

$$R := \sqrt{R_o^2 + h^2 + 2 \cdot R_o \cdot h \cdot \cos\left[\phi - \phi_{gc}\right]}$$

by including altitude of radar site, now have true distance from ECI centre to radar site

$R = 6366.8079 \cdot \mathrm{km}$

ECI coordinates for the site at the satellite rise and set times are:

$$\begin{bmatrix} Rris_{I_r} \\ Rris_{J_r} \\ Rris_{K_r} \end{bmatrix} := \begin{bmatrix} \cos\left[\theta ris_r\right] & -\sin\left[\theta ris_r\right] & 0 \\ \sin\left[\theta ris_r\right] & \cos\left[\theta ris_r\right] & 0 \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} R \cdot \cos\left[\phi_{gc}\right] \\ 0 \cdot \mathrm{km} \\ R \cdot \sin\left[\phi_{gc}\right] \end{bmatrix}$$

$$\begin{bmatrix} Rset_{I_r} \\ Rset_{J_r} \\ Rset_{K_r} \end{bmatrix} := \begin{bmatrix} \cos\left[\theta set_r\right] & -\sin\left[\theta set_r\right] & 0 \\ \sin\left[\theta set_r\right] & \cos\left[\theta set_r\right] & 0 \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} R \cdot \cos\left[\phi_{gc}\right] \\ 0 \cdot \mathrm{km} \\ R \cdot \sin\left[\phi_{gc}\right] \end{bmatrix}$$

$$\begin{bmatrix} Rris_{I_j} \\ Rris_{J_j} \\ Rris_{K_j} \end{bmatrix} = \begin{vmatrix} 4082.8821 \\ -1546.2663 \\ 4634.1534 \end{vmatrix} \cdot \mathrm{km} \qquad \begin{bmatrix} Rset_{I_j} \\ Rset_{J_j} \\ Rset_{K_j} \end{bmatrix} = \begin{vmatrix} 3572.0568 \\ 2510.2342 \\ 4634.1534 \end{vmatrix} \cdot \mathrm{km}$$

4. Calculate PQW (Perifocal) coordinates of the satellite at the rise and set times.

Obtain the satellite orbital elements from a file containing selected portions of the NORAD two-line element sets.

satdatel := READPRN(elements)

$$\text{satel} := \left(\text{satdatel}^{T}\right)^{\langle 10\rangle}$$

$$\text{sat} := \text{satel}^{T}$$

Select the desired satellite: in this case M 1 and choose the elements for that satellite

$$\left(\text{sat}^{T}\right)^{\langle j\rangle} = \begin{vmatrix} 197.25939867 \\ -0.00000015 \\ 64.8901 \\ 37.9878 \\ 0.0021686 \\ 210.675 \\ 149.2556 \\ 2.13102429 \end{vmatrix}$$

$$\text{EJD} := \left|\text{sat}^{\langle 1\rangle}\right| \cdot \text{day}$$

Julian Day of Satellite Epoch for 1990

$$\text{EJD} = 197.25939867 \cdot \text{day}$$

$$\text{ndot} := \text{sat}^{\langle 2\rangle} \cdot \frac{\text{rev}}{\text{day}^{2}}$$

First Time Derivative of the Mean Motion

$$\text{ndot} = -0.00000015 \cdot \frac{\text{rev}}{\text{day}^{2}}$$

$$i_{o} := \left|\text{sat}^{\langle 3\rangle}\right| \cdot \text{deg}$$

Inclination of the orbit

$$i_{o} = 64.8901 \cdot \text{deg} \qquad i_{o} = 1.1325 \cdot \text{rad}$$

$$\Omega_{o} := \left|\text{sat}^{\langle 4\rangle}\right| \cdot \text{deg}$$

Right Ascension of the Ascending Node

$$\Omega_{o} = 37.9878 \cdot \text{deg} \qquad \Omega_{o} = 0.663 \cdot \text{rad}$$

$$e := \left|\text{sat}^{\langle 5\rangle}\right|$$

Eccentricity of the orbit

$$e = 0.0021686$$

5. **Calculate ECI Coordinates of the satellite at the rise and set times**

Define rotation matrix to convert PQW to ECI reference frame for the rise time of the satellite

$$R11_{ris_r} := \cos\left[\Omega_{ris_r}\right]\cdot\cos\left[\omega_{ris_r}\right] - \sin\left[\Omega_{ris_r}\right]\cdot\sin\left[\omega_{ris_r}\right]\cdot\cos\left[i_o\right]$$

$$R12_{ris_r} := -\cos\left[\Omega_{ris_r}\right]\cdot\sin\left[\omega_{ris_r}\right] - \sin\left[\Omega_{ris_r}\right]\cdot\cos\left[\omega_{ris_r}\right]\cdot\cos\left[i_o\right]$$

$$R13_{ris_r} := \sin\left[\Omega_{ris_r}\right]\cdot\sin\left[i_o\right]$$

$$R21_{ris_r} := \sin\left[\Omega_{ris_r}\right]\cdot\cos\left[\omega_{ris_r}\right] + \cos\left[\Omega_{ris_r}\right]\cdot\sin\left[\omega_{ris_r}\right]\cdot\cos\left[i_o\right]$$

$$R22_{ris_r} := -\sin\left[\Omega_{ris_r}\right]\cdot\sin\left[\omega_{ris_r}\right] + \cos\left[\Omega_{ris_r}\right]\cdot\cos\left[\omega_{ris_r}\right]\cdot\cos\left[i_o\right]$$

$$R23_{ris_r} := -\cos\left[\Omega_{ris_r}\right]\cdot\sin\left[i_o\right]$$

$$R31_{ris_r} := \sin\left[\omega_{ris_r}\right]\cdot\sin\left[i_o\right]$$

$$R32_{ris_r} := \cos\left[\omega_{ris_r}\right]\cdot\sin\left[i_o\right] \qquad R33_{ris_r} := \cos\left[i_o\right]$$

6. Create rotation matrices to convert ECI coordinates to satellite coordinate frame: "b" frame.

Calculate the velocity vectors of the satellite

$$V_{ris.P} := -\sin v_{ris} \cdot \sqrt{\frac{\mu}{p}} \qquad V_{set.P} := -\sin v_{set} \cdot \sqrt{\frac{\mu}{p}}$$

$$V_{ris.Q} := \left[e + \cos v_{ris}\right] \cdot \sqrt{\frac{\mu}{p}} \qquad V_{set.Q} := \left[e + \cos v_{set}\right] \cdot \sqrt{\frac{\mu}{p}}$$

$$V_{ris.W_r} := 0 \cdot \frac{km}{sec} \qquad V_{set.W_r} := 0 \cdot \frac{km}{sec}$$

$$\begin{bmatrix} V_{ris.P_j} \\ V_{ris.Q_j} \\ V_{ris.W_j} \end{bmatrix} = \begin{vmatrix} -2299.4693 \\ -3206.8605 \\ 0 \end{vmatrix} \cdot \frac{m}{sec} \qquad \begin{bmatrix} V_{set.P_j} \\ V_{set.Q_j} \\ V_{set.W_j} \end{bmatrix} = \begin{vmatrix} 3921.0866 \\ -493.073 \\ 0 \end{vmatrix} \cdot \frac{m}{sec}$$

Define h vector (vector perpendicular to orbital plane), which is found by r X V

$$h_{ris.P_r} := 0 \cdot \frac{m^2}{sec} \qquad h_{ris.Q_r} := 0 \cdot \frac{m^2}{sec}$$

$$h_{ris.W_r} := r_{ris.P_r} \cdot V_{ris.Q_r} - r_{ris.Q_r} \cdot V_{ris.P_r}$$

$$\begin{bmatrix} R11_{ris_j} & R12_{ris_j} & R13_{ris_j} \\ R21_{ris_j} & R22_{ris_j} & R23_{ris_j} \\ R31_{ris_j} & R32_{ris_j} & R33_{ris_j} \end{bmatrix} = \begin{vmatrix} -0.5653 & 0.6254 & 0.5378 \\ -0.685 & 0.0072 & -0.7285 \\ -0.4595 & -0.7803 & 0.4244 \end{vmatrix}$$

$$\begin{bmatrix} R11_{set_j} & R12_{set_j} & R13_{set_j} \\ R21_{set_j} & R22_{set_j} & R23_{set_j} \\ R31_{set_j} & R32_{set_j} & R33_{set_j} \end{bmatrix} = \begin{vmatrix} -0.5654 & 0.6254 & 0.5377 \\ -0.685 & 0.0071 & -0.7285 \\ -0.4595 & -0.7803 & 0.4244 \end{vmatrix}$$

The radius vector from the centre of the ECI coordinate frame (Earth's centre) to the satellite expressed in ECI coordinates is given by:

$$\begin{bmatrix} r_{ris.I_r} \\ r_{ris.J_r} \\ r_{ris.K_r} \end{bmatrix} := \begin{bmatrix} R11_{ris_r} & R12_{ris_r} & R13_{ris_r} \\ R21_{ris_r} & R22_{ris_r} & R23_{ris_r} \\ R31_{ris_r} & R32_{ris_r} & R33_{ris_r} \end{bmatrix} \cdot \begin{bmatrix} r_{ris.P_r} \\ r_{ris.Q_r} \\ r_{ris.W_r} \end{bmatrix}$$

$$\begin{bmatrix} r_{ris.I_j} \\ r_{ris.J_j} \\ r_{ris.K_j} \end{bmatrix} = \begin{vmatrix} 21046.9158 \\ 14345.3085 \\ -2047.5581 \end{vmatrix} \cdot km$$

$$r_{ris.ECI_r} := \sqrt{\left(r_{ris.I_r}\right)^2 + \left(r_{ris.J_r}\right)^2 + \left(r_{ris.K_r}\right)^2}$$ The scalar value of the radius vector at the rise time

Define rotation matrix to convert PQW to ECI reference frame for the setting time of the satellite

$$R11_{set_r} := \cos\left[\Omega_{set_r}\right]\cdot\cos\left[\omega_{set_r}\right] - \sin\left[\Omega_{set_r}\right]\cdot\sin\left[\omega_{set_r}\right]\cdot\cos\left[i_o\right]$$

$$R12_{set_r} := -\cos\left[\Omega_{set_r}\right]\cdot\sin\left[\omega_{set_r}\right] - \sin\left[\Omega_{set_r}\right]\cdot\cos\left[\omega_{set_r}\right]\cdot\cos\left[i_o\right]$$

$$R13_{set_r} := \sin\left[\Omega_{set_r}\right]\cdot\sin\left[i_o\right]$$

$$R21_{set_r} := \sin\left[\Omega_{set_r}\right]\cdot\cos\left[\omega_{set_r}\right] + \cos\left[\Omega_{set_r}\right]\cdot\sin\left[\omega_{set_r}\right]\cdot\cos\left[i_o\right]$$

$$R22_{set_r} := -\sin\left[\Omega_{set_r}\right]\cdot\sin\left[\omega_{set_r}\right] + \cos\left[\Omega_{set_r}\right]\cdot\cos\left[\omega_{set_r}\right]\cdot\cos\left[i_o\right]$$

$$R23_{set_r} := -\cos\left[\Omega_{set_r}\right]\cdot\sin\left[i_o\right]$$

$$R31_{set_r} := \sin\left[\omega_{set_r}\right]\cdot\sin\left[i_o\right]$$

$$R32_{set_r} := \cos\left[\omega_{set_r}\right]\cdot\sin\left[i_o\right]$$

$$R33_{set_r} := \cos\left[i_o\right]$$

components of the radius vector in the PQW reference frame, the orbital reference frame (Perifocal)

$$r_{ris.P_r} := r_{ris_r} \cdot \cos v_{ris_r}$$

$$r_{ris.Q_r} := r_{ris_r} \cdot \sin v_{ris_r}$$

$$r_{ris.W_r} := 0 \cdot km$$

$$r_{set.P_r} := r_{set_r} \cdot \cos v_{set_r}$$

$$r_{set.Q_r} := r_{set_r} \cdot \sin v_{set_r}$$

$$r_{set.W_r} := 0 \cdot km$$

$$\begin{bmatrix} r_{ris.P_j} \\ r_{ris.Q_j} \\ r_{ris.W_j} \end{bmatrix} = \begin{vmatrix} -20784.9331 \\ 14864.0367 \\ 0 \end{vmatrix} \cdot km$$

$$\begin{bmatrix} r_{set.P_j} \\ r_{set.Q_j} \\ r_{set.W_j} \end{bmatrix} = \begin{vmatrix} -3237.8665 \\ -25308.615 \\ 0 \end{vmatrix} \cdot km$$

$$\begin{bmatrix} r_{set.I_r} \\ r_{set.J_r} \\ r_{set.K_r} \end{bmatrix} := \begin{bmatrix} R11_{set_r} & R12_{set_r} & R13_{set_r} \\ R21_{set_r} & R22_{set_r} & R23_{set_r} \\ R31_{set_r} & R32_{set_r} & R33_{set_r} \end{bmatrix} \cdot \begin{bmatrix} r_{set.P_r} \\ r_{set.Q_r} \\ r_{set.W_r} \end{bmatrix}$$

$$\begin{bmatrix} r_{set.I_j} \\ r_{set.J_j} \\ r_{set.K_j} \end{bmatrix} = \begin{vmatrix} -13997.5611 \\ 2037.177 \\ 21235.0645 \end{vmatrix} \cdot km$$

$$r_{set.ECI_r} := \sqrt{r_{set.I_r}^{\ 2} + r_{set.J_r}^{\ 2} + r_{set.K_r}^{\ 2}}$$

The scalar value of the radius vector at the set time

$r_{ris.ECI_j} = 25552.9457 \cdot km$ $\qquad r_{set.ECI_j} = 25514.8931 \cdot km$

Recall from earlier calculations, the scalar value of the satellite distance from the focal point about which the ellipse of the orbit was formed (centre of the Earth)

$r_{ris_j} = 25552.9457 \cdot km$ $\qquad r_{set_j} = 25514.8931 \cdot km$

Which confirms the accuracy of the rotation matrices

cosine of true anomoly, v, at time of rise and setting

$$cosv_{ris_r} := \frac{e - \cos\left[E_{ris_r}\right]}{e \cdot \cos\left[E_{ris_r}\right] - 1} \qquad cosv_{ris_j} = -0.8134$$

$$cosv_{set_r} := \frac{e - \cos\left[E_{set_r}\right]}{e \cdot \cos\left[E_{set_r}\right] - 1} \qquad cosv_{set_j} = -0.1269$$

$$r_{ris_r} := a \cdot \left[1 - e \cdot \cos\left[E_{ris_r}\right]\right]$$

scalar distance from satellite to centre of ECI coordinate frame at time of rise

$$r_{set_r} := a \cdot \left[1 - e \cdot \cos\left[E_{set_r}\right]\right]$$

scalar distance from satellite to centre of ECI coordinate frame at time of setting

$$r_{ris_j} = 25552.9457 \cdot km \qquad r_{set_j} = 25514.8931 \cdot km$$

sine of true anomoly, v, at time of rise and setting

$$sinv_{ris_r} := \frac{a \cdot \sqrt{1 - e^2}}{r_{ris_r}} \cdot \sin\left[E_{ris_r}\right] \qquad sinv_{ris_j} = 0.5817$$

$$sinv_{set_r} := \frac{a \cdot \sqrt{1 - e^2}}{r_{set_r}} \cdot \sin\left[E_{set_r}\right] \qquad sinv_{set_j} = -0.9919$$

Read in rise and set times (JD.HMS format for the year using 0 hrs UT 1 Jan 90 as 1.000000) for a satellite as observed by the radar site

satdat := READPRN(s6cs2079)   nrows := rows(satdat)   nrows = 64

j := 1   j is the subscript used to show results for the first number in a set of results where examples are shown

$$\left(satdat^{T}\right)^{\langle j\rangle^{T}} = (244.041734\ \ 244.080019)$$

two columns representing rise and set times

r := 1 ..nrows

Convert JD.HMS format to decimal format of JD (Julian Day)

NOTE: In using the floor function, 0.1 is added to correct for any calculation errors due to machine limitations.
E.g. Due to calculations in previous floor and multiplication operations, the seconds value before the floor operation may turn out to be 39.999... vice 40, which would result in an erroneous seconds value of 39 after the floor function. In one extreme case where the last four digits were 3800, MathCAD calculations resulted in a minutes value of 37 and a seconds value of 100. The inclusion of the 0.1 in the floor function has corrected this error and the correct integer values are given for the breakdown of the time data.

Rise Times

$$t_{dris_r} := \mathrm{floor}\left[satdat_{r,1} + 0.1\right] \qquad t_{dris_j} = 244$$

$$satdatr1 := 100\cdot\left[satdat^{\langle 1\rangle} - t_{dris}\right]$$

$$t_{hris_r} := \mathrm{floor}\left[satdatr1_r + 0.1\right] \qquad t_{hris_j} = 4$$

$$satdatr2 := \left[satdatr1 - t_{hris}\right]\cdot 100$$

$$t_{mris_r} := \mathrm{floor}\left[satdatr2_r + 0.1\right] \qquad t_{mris_j} = 17$$

$$satdatr3 := \left[satdatr2 - t_{mris}\right] \cdot 100$$

$$t_{sris_r} := \mathrm{floor}\left[satdatr3_r + 0.1\right] \qquad t_{sris_j} = 34$$

$$t_{ris} := \left[t_{dris} + \frac{t_{hris}}{24} + \frac{t_{mris}}{24 \cdot 60} + \frac{t_{sris}}{24 \cdot 60 \cdot 60}\right] \cdot day$$

Set times

$$t_{dset_r} := \mathrm{floor}\left[satdat_{r,2} + 0.1\right] \qquad t_{dset_j} = 244$$

$$satdats1 := 100 \cdot \left[satdat^{\langle 2 \rangle} - t_{dset}\right]$$

$$t_{hset_r} := \mathrm{floor}\left[satdats1_r + 0.1\right] \qquad t_{hset_j} = 8$$

$$satdats2 := \left[satdats1 - t_{hset}\right] \cdot 100$$

$$t_{mset_r} := \mathrm{floor}\left[satdats2_r + 0.1\right] \qquad t_{mset_j} = 0$$

$$satdats3 := \left[satdats2 - t_{mset}\right] \cdot 100$$

$$t_{sset_r} := \mathrm{floor}\left[satdats3_r + 0.1\right] \qquad t_{sset_j} = 19$$

$$t_{set} := \left[t_{dset} + \frac{t_{hset}}{24} + \frac{t_{mset}}{24 \cdot 60} + \frac{t_{sset}}{24 \cdot 60 \cdot 60}\right] \cdot day$$

$$h_{set.P_r} := 0 \cdot \frac{m^2}{sec} \qquad h_{set.Q_r} := 0 \cdot \frac{m^2}{sec}$$

$$h_{set.W_r} := r_{set.P_r} \cdot V_{set.Q_r} - r_{set.Q_r} \cdot V_{set.P_r}$$

$$\begin{bmatrix} h_{ris.P_j} \\ h_{ris.Q_j} \\ h_{ris.W_j} \end{bmatrix} = \begin{vmatrix} 0 \\ 0 \\ 100833.7757 \end{vmatrix} \cdot \frac{km^2}{sec} \qquad \begin{bmatrix} h_{set.P_j} \\ h_{set.Q_j} \\ h_{set.W_j} \end{bmatrix} = \begin{vmatrix} 0 \\ 0 \\ 100833.7757 \end{vmatrix} \cdot \frac{km^2}{sec}$$

Confirmation that the h vectors are correct is shown by their being identical, since in an orbit, the cross product of the r and V vectors (h) is constant

Normalizing the h vector:

$$H_{ris.P_r} := 0 \qquad H_{ris.Q_r} := 0 \qquad H_{ris.W_r} := 1$$

$$H_{set.P_r} := 0 \qquad H_{set.Q_r} := 0 \qquad H_{set.W_r} := 1$$

$$\begin{bmatrix} H_{ris.P_j} \\ H_{ris.Q_j} \\ H_{ris.W_j} \end{bmatrix} = \begin{vmatrix} 0 \\ 0 \\ 1 \end{vmatrix} \qquad \begin{bmatrix} H_{set.P_j} \\ H_{set.Q_j} \\ H_{set.W_j} \end{bmatrix} = \begin{vmatrix} 0 \\ 0 \\ 1 \end{vmatrix}$$

Convert H vectors to ECI coordinates

$$\begin{bmatrix} H_{ris.I_r} \\ H_{ris.J_r} \\ H_{ris.K_r} \end{bmatrix} := \begin{bmatrix} R11_{ris_r} & R12_{ris_r} & R13_{ris_r} \\ R21_{ris_r} & R22_{ris_r} & R23_{ris_r} \\ R31_{ris_r} & R32_{ris_r} & R33_{ris_r} \end{bmatrix} \cdot \begin{bmatrix} H_{ris.P_r} \\ H_{ris.Q_r} \\ H_{ris.W_r} \end{bmatrix}$$

$$\begin{bmatrix} H_{set.I_r} \\ H_{set.J_r} \\ H_{set.K_r} \end{bmatrix} := \begin{bmatrix} R11_{set_r} & R12_{set_r} & R13_{set_r} \\ R21_{set_r} & R22_{set_r} & R23_{set_r} \\ R31_{set_r} & R32_{set_r} & R33_{set_r} \end{bmatrix} \cdot \begin{bmatrix} H_{set.P_r} \\ H_{set.Q_r} \\ H_{set.W_r} \end{bmatrix}$$

$$\begin{bmatrix} H_{ris.I_j} \\ H_{ris.J_j} \\ H_{ris.K_j} \end{bmatrix} = \begin{vmatrix} 0.5378 \\ -0.7285 \\ 0.4244 \end{vmatrix} \qquad \begin{bmatrix} H_{set.I_j} \\ H_{set.J_j} \\ H_{set.K_j} \end{bmatrix} = \begin{vmatrix} 0.5377 \\ -0.7285 \\ 0.4244 \end{vmatrix}$$

Normalize radius vectors (ECI coordinates) to become row 1 of the rotation matrices to convert ECI coordinates to the "b" frame

$$Rb11_{ris_r} := \frac{r_{ris.I_r}}{\left| r_{ris.ECI_r} \right|} \qquad Rb11_{set_r} := \frac{r_{set.I_r}}{\left| r_{set.ECI_r} \right|}$$

$$Rb12_{ris_r} := \frac{r_{ris.J_r}}{\left| r_{ris.ECI_r} \right|} \qquad Rb12_{set_r} := \frac{r_{set.J_r}}{\left| r_{set.ECI_r} \right|}$$

$$Rb13_{ris_r} := \frac{r_{ris.K_r}}{\left| r_{ris.ECI_r} \right|} \qquad Rb13_{set_r} := \frac{r_{set.K_r}}{\left| r_{set.ECI_r} \right|}$$

$$\sqrt{\left(Rb11_{ris_1}\right)^2 + \left(Rb12_{ris_1}\right)^2 + \left(Rb13_{ris_1}\right)^2} = 1$$

Confirmation that the vectors are normalized

$$\sqrt{\left(Rb11_{set_1}\right)^2 + \left(Rb12_{set_1}\right)^2 + \left(Rb13_{set_1}\right)^2} = 1$$

The normalized h vectors in ECI coordinates become row 3 of the ECI to b rotation matrices

$$Rb31_{ris} := H_{ris.I} \qquad Rb31_{set} := H_{set.I}$$

$$Rb32_{ris} := H_{ris.J} \qquad Rb32_{set} := H_{set.J}$$

$$Rb33_{ris} := H_{ris.K} \qquad Rb33_{set} := H_{set.K}$$

$$\sqrt{\left(Rb31_{ris_1}\right)^2 + \left(Rb32_{ris_1}\right)^2 + \left(Rb33_{ris_1}\right)^2} = 1$$

Confirmation that the vectors are normalized

$$\sqrt{{Rb31_{set_1}}^2 + {Rb32_{set_1}}^2 + {Rb33_{set_1}}^2} = 1$$

The b1 and b3 vectors are the first and third rows of the ECI to b rotation matrices. The second row is formed by the vector created by the cross product of the b3 and b1 vectors

$$b1 := \begin{bmatrix} Rb11 \\ Rb12 \\ Rb13 \end{bmatrix} \qquad b3 := \begin{bmatrix} Rb31 \\ Rb32 \\ Rb33 \end{bmatrix} \qquad b2 := b3 \times b1$$

$$Rb21_{ris_r} := Rb32_{ris_r} \cdot Rb13_{ris_r} - Rb33_{ris_r} \cdot Rb12_{ris_r}$$

$$Rb22_{ris_r} := Rb33_{ris_r} \cdot Rb11_{ris_r} - Rb31_{ris_r} \cdot Rb13_{ris_r}$$

$$Rb23_{ris_r} := Rb31_{ris_r} \cdot Rb12_{ris_r} - Rb32_{ris_r} \cdot Rb11_{ris_r}$$

$$\sqrt{{Rb21_{ris_1}}^2 + {Rb22_{ris_1}}^2 + {Rb23_{ris_1}}^2} = 1$$

Confirmation that the vectors are normalized

$$Rb21_{set_r} := Rb32_{set_r} \cdot Rb13_{set_r} - Rb33_{set_r} \cdot Rb12_{set_r}$$

$$Rb22_{set_r} := Rb33_{set_r} \cdot Rb11_{set_r} - Rb31_{set_r} \cdot Rb13_{set_r}$$

$$Rb23_{set_r} := Rb31_{set_r} \cdot Rb12_{set_r} - Rb32_{set_r} \cdot Rb11_{set_r}$$

$$\sqrt{{Rb21_{set_1}}^2 + {Rb22_{set_1}}^2 + {Rb23_{set_1}}^2} = 1$$

Confirmation that the vectors are normalized

Rotation matrix to convert from ECI to the satellite frame which will be called the "b" frame.

$$\begin{bmatrix} Rb11 & Rb12 & Rb13 \\ Rb21 & Rb22 & Rb23 \\ Rb31 & Rb32 & Rb33 \end{bmatrix}$$

$$\begin{bmatrix} Rb11_{ris_j} & Rb12_{ris_j} & Rb13_{ris_j} \\ Rb21_{ris_j} & Rb22_{ris_j} & Rb23_{ris_j} \\ Rb31_{ris_j} & Rb32_{ris_j} & Rb33_{ris_j} \end{bmatrix} = \begin{vmatrix} 0.8237 & 0.5614 & -0.0801 \\ -0.1799 & 0.3926 & 0.9019 \\ 0.5378 & -0.7285 & 0.4244 \end{vmatrix}$$

$$\begin{bmatrix} Rb11_{set_j} & Rb12_{set_j} & Rb13_{set_j} \\ Rb21_{set_j} & Rb22_{set_j} & Rb23_{set_j} \\ Rb31_{set_j} & Rb32_{set_j} & Rb33_{set_j} \end{bmatrix} = \begin{vmatrix} -0.5486 & 0.0798 & 0.8323 \\ -0.6402 & -0.6803 & -0.3567 \\ 0.5377 & -0.7285 & 0.4244 \end{vmatrix}$$

7. Calculate vector from observing site to satellite (in ECI coordinates)

$$\begin{bmatrix} \rho_{ris.I_r} \\ \rho_{ris.J_r} \\ \rho_{ris.K_r} \end{bmatrix} := \begin{bmatrix} r_{ris.I_r} \\ r_{ris.J_r} \\ r_{ris.K_r} \end{bmatrix} - \begin{bmatrix} Rris_{I_r} \\ Rris_{J_r} \\ Rris_{K_r} \end{bmatrix} \qquad \begin{bmatrix} \rho_{ris.I_j} \\ \rho_{ris.J_j} \\ \rho_{ris.K_j} \end{bmatrix} = \begin{vmatrix} 16964.0337 \\ 15891.5748 \\ -6681.7114 \end{vmatrix} \cdot km$$

$$\begin{bmatrix} \rho_{set.I_r} \\ \rho_{set.J_r} \\ \rho_{set.K_r} \end{bmatrix} := \begin{bmatrix} r_{set.I_r} \\ r_{set.J_r} \\ r_{set.K_r} \end{bmatrix} - \begin{bmatrix} Rset_{I_r} \\ Rset_{J_r} \\ Rset_{K_r} \end{bmatrix} \qquad \begin{bmatrix} \rho_{set.I_j} \\ \rho_{set.J_j} \\ \rho_{set.K_j} \end{bmatrix} = \begin{vmatrix} -17569.6179 \\ -473.0572 \\ 16600.9111 \end{vmatrix} \cdot km$$

8. Just to confirm that the calculations to ECI have been accurate, the ECI coordinates are converted to the radar reference frame (SEZ) and azimuth and elevation are calculated and compared to the PASSCHED program results.

$$\begin{bmatrix} \rho_{ris.S_r} \\ \rho_{ris.E_r} \\ \rho_{ris.Z_r} \end{bmatrix} := \begin{bmatrix} \sin(\phi)\cdot\cos\left[\theta ris_r\right] & \sin(\phi)\cdot\sin\left[\theta ris_r\right] & -\cos(\phi) \\ -\sin\left[\theta ris_r\right] & \cos\left[\theta ris_r\right] & 0 \\ \cos(\phi)\cdot\cos\left[\theta ris_r\right] & \cos(\phi)\cdot\sin\left[\theta ris_r\right] & \sin(\phi) \end{bmatrix} \cdot \begin{bmatrix} \rho_{ris.I_r} \\ \rho_{ris.J_r} \\ \rho_{ris.K_r} \end{bmatrix}$$

$$\begin{bmatrix} \rho_{set.S_r} \\ \rho_{set.E_r} \\ \rho_{set.Z_r} \end{bmatrix} := \begin{bmatrix} \sin(\phi)\cdot\cos\left[\theta set_r\right] & \sin(\phi)\cdot\sin\left[\theta set_r\right] & -\cos(\phi) \\ -\sin\left[\theta set_r\right] & \cos\left[\theta set_r\right] & 0 \\ \cos(\phi)\cdot\cos\left[\theta set_r\right] & \cos(\phi)\cdot\sin\left[\theta set_r\right] & \sin(\phi) \end{bmatrix} \cdot \begin{bmatrix} \rho_{set.I_r} \\ \rho_{set.J_r} \\ \rho_{set.K_r} \end{bmatrix}$$

$$\begin{bmatrix} \rho_{ris.S_j} \\ \rho_{ris.E_j} \\ \rho_{ris.Z_j} \end{bmatrix} = \begin{vmatrix} 12039.4331 \\ 20869.6623 \\ 2115.4431 \end{vmatrix} \cdot km \qquad \begin{bmatrix} \rho_{set.S_j} \\ \rho_{set.E_j} \\ \rho_{set.Z_j} \end{bmatrix} = \begin{vmatrix} -22037.7054 \\ 9714.9065 \\ 2113.2055 \end{vmatrix} \cdot km$$

$$El_{ris_r} := \operatorname{asin}\left[\frac{\rho_{ris.Z_r}}{\sqrt{\left(\rho_{ris.S_r}\right)^2 + \left(\rho_{ris.E_r}\right)^2 + \left(\rho_{ris.Z_r}\right)^2}}\right]$$

$$Az_{ris_r} := \operatorname{mod}\left[\operatorname{angle}\left[\rho_{ris.S_r}, -\rho_{ris.E_r}\right] + \pi, 2\cdot\pi\right]$$

$$El_{set_r} := \operatorname{asin}\left[\frac{\rho_{set.Z_r}}{\sqrt{\left(\rho_{set.S_r}\right)^2 + \left(\rho_{set.E_r}\right)^2 + \left(\rho_{set.Z_r}\right)^2}}\right]$$

$$Az_{set_r} := \operatorname{mod}\left[\operatorname{angle}\left[\rho_{set.S_r}, -\rho_{set.E_r}\right] + \pi, 2\cdot\pi\right]$$

$El_{ris_j} = 5.0178\cdot deg$ $\qquad$ $Az_{ris_j} = 119.9801\cdot deg$

From PASSCHED, at rise time: El = 5 deg; Az = 120 deg

$El_{set_j} = 5.0145\cdot deg$ $\qquad$ $Az_{set_j} = 23.7894\cdot deg$

From PASSCHED, at set time: El = 5 deg; Az = 24 deg

Figures in agreement

9. Convert radar site-to-satellite vector from the ECI coordinate frame to the satellite coordinate frame.

$$\begin{bmatrix} \rho_{ris.b1_r} \\ \rho_{ris.b2_r} \\ \rho_{ris.b3_r} \end{bmatrix} := \begin{bmatrix} Rb11_{ris_r} & Rb12_{ris_r} & Rb13_{ris_r} \\ Rb21_{ris_r} & Rb22_{ris_r} & Rb23_{ris_r} \\ Rb31_{ris_r} & Rb32_{ris_r} & Rb33_{ris_r} \end{bmatrix} \cdot \begin{bmatrix} \rho_{ris.I_r} \\ \rho_{ris.J_r} \\ \rho_{ris.K_r} \end{bmatrix}$$

$$\begin{bmatrix} \rho_{set.b1_r} \\ \rho_{set.b2_r} \\ \rho_{set.b3_r} \end{bmatrix} := \begin{bmatrix} Rb11_{set_r} & Rb12_{set_r} & Rb13_{set_r} \\ Rb21_{set_r} & Rb22_{set_r} & Rb23_{set_r} \\ Rb31_{set_r} & Rb32_{set_r} & Rb33_{set_r} \end{bmatrix} \cdot \begin{bmatrix} \rho_{set.I_r} \\ \rho_{set.J_r} \\ \rho_{set.K_r} \end{bmatrix}$$

$$\begin{bmatrix} \rho_{ris.b1_j} \\ \rho_{ris.b2_j} \\ \rho_{ris.b3_j} \end{bmatrix} = \begin{vmatrix} 23429.4445 \\ -2838.3087 \\ -5288.7607 \end{vmatrix} \cdot km \qquad \begin{bmatrix} \rho_{set.b1_j} \\ \rho_{set.b2_j} \\ \rho_{set.b3_j} \end{bmatrix} = \begin{vmatrix} 23417.2847 \\ 5647.8724 \\ -2058.5966 \end{vmatrix} \cdot km$$

10. Confirm that ECI to "b" rotation is correct; that is, b1 axis is in line with the radius vector from the ECI origin to the "b" frame origin.

$$\begin{bmatrix} r_{ris.b1_r} \\ r_{ris.b2_r} \\ r_{ris.b3_r} \end{bmatrix} := \begin{bmatrix} Rb11_{ris_r} & Rb12_{ris_r} & Rb13_{ris_r} \\ Rb21_{ris_r} & Rb22_{ris_r} & Rb23_{ris_r} \\ Rb31_{ris_r} & Rb32_{ris_r} & Rb33_{ris_r} \end{bmatrix} \cdot \begin{bmatrix} r_{ris.I_r} \\ r_{ris.J_r} \\ r_{ris.K_r} \end{bmatrix}$$

$$\begin{bmatrix} r_{ris.b1_j} \\ r_{ris.b2_j} \\ r_{ris.b3_j} \end{bmatrix} = \begin{bmatrix} 25552.9457 \\ 0 \\ 0 \end{bmatrix} \cdot km \qquad r_{ris.ECI_j} = 25552.9457 \cdot km$$

Works for this rotation

$$\begin{bmatrix} r_{set.b1_r} \\ r_{set.b2_r} \\ r_{set.b3_r} \end{bmatrix} := \begin{bmatrix} Rb11_{set_r} & Rb12_{set_r} & Rb13_{set_r} \\ Rb21_{set_r} & Rb22_{set_r} & Rb23_{set_r} \\ Rb31_{set_r} & Rb32_{set_r} & Rb33_{set_r} \end{bmatrix} \cdot \begin{bmatrix} r_{set.I_r} \\ r_{set.J_r} \\ r_{set.K_r} \end{bmatrix}$$

$$\begin{bmatrix} r_{set.b1_j} \\ r_{set.b2_j} \\ r_{set.b3_j} \end{bmatrix} = \begin{bmatrix} 25514.8931 \\ 0 \\ 0 \end{bmatrix} \cdot km \qquad r_{set.ECI_j} = 25514.8931 \cdot km$$

Confirmed again

11. Calculate effective angle of rotation that radar beam sees the satellite rotate through.

Effective angle of rotation is the difference between the rise and set vectors from the radar site to the satellite (in the satellite coordinate frame)

$$\delta\theta_r := \operatorname{acos}\left[\frac{\begin{bmatrix} \rho_{ris.b1_r} \\ \rho_{ris.b2_r} \\ \rho_{ris.b3_r} \end{bmatrix} \cdot \begin{bmatrix} \rho_{set.b1_r} \\ \rho_{set.b2_r} \\ \rho_{set.b3_r} \end{bmatrix}}{\left|\begin{bmatrix} \rho_{ris.b1_r} \\ \rho_{ris.b2_r} \\ \rho_{ris.b3_r} \end{bmatrix}\right| \cdot \left|\begin{bmatrix} \rho_{set.b1_r} \\ \rho_{set.b2_r} \\ \rho_{set.b3_r} \end{bmatrix}\right|}\right]$$

$\delta\theta_j = 21.6432 \cdot deg$

$\left|Az_{set_j} - Az_{ris_j}\right| = 96.1907 \cdot deg$

Notice that the effective angular rotation is not the same as the difference between the rise and set azimuths, and in some cases, the difference can be quite large

12. Calculate the minimum angular rotation required for the radar to obtain a radar image.

$f := 10^{10} \cdot Hz$ frequency of radar is 10 GHz

$c := 2.997925 \cdot 10^{8} \cdot \frac{m}{sec}$ velocity of light (and radio waves)

$\lambda := \frac{c}{f}$ $\lambda = 0.02998 \cdot m$ average wavelength of the radar

$\delta := 0.12 \cdot m$ desired cross range resolution

$\theta min := asin\left[\frac{\lambda}{2 \cdot \delta}\right]$ minimum angular rotation to obtain cross range resolution

$\theta min = 7.1758 \cdot deg$

13. Calculate the number of opportunities that the radar was capable of imaging the satellite in the 31 day period presented and compare with the total number of satellite passes.

$n_{obs} := \sum_{r} if\left[\delta\theta_{r} \geq \theta min, 1, 0\right]$ Count the number of observations that meet the minimum effective angular rotation requirement

$n_{obs} = 56$ $nrows = 64$ The number of radar resolutions out of the total number of satellite passes

UNIT DEFINITIONS MKS (SI) UNIT SYSTEM

I. Base Units

$m \equiv 1L$ $kg \equiv 1M$ $sec \equiv 1T$

II. Angular Measure

$rad \equiv 1$ $deg \equiv \frac{\pi}{180} \cdot rad$ $rev \equiv 360 \cdot deg$

III. Derived Units: Length

$cm \equiv 0.01 \cdot m$ $km \equiv 1000 \cdot m$ $mm \equiv 0.001 \cdot m$

$ft \equiv 0.3048 \cdot m$ $in \equiv 2.54 \cdot cm$ $mi \equiv 5280 \cdot ft$

IV. Derived Units: Mass

$gm \equiv 10^{-3} \cdot kg$ $lb \equiv 453.59247 \cdot gm$ use convention that lb represents pounds mass

V. Derived Units: Time

$min \equiv 60 \cdot sec$ $hr \equiv 3600 \cdot sec$ $day \equiv 24 \cdot hr$

$yr \equiv 365.2422 \cdot day$ (tropical year)

VI. Derived Units: Velocity

$mph \equiv \frac{mi}{hr}$ $kph := \frac{km}{hr}$

VII. Derived Units: Other

$Hz \equiv sec^{-1}$

$ORIGIN \equiv 1$ $TOL \equiv 10^{-10}$

Appendix C. *MIP-83 Formulation And Solution* ($p = 1$)

```
MIP83 maxproj output maxproj.dat

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  San Marino, California  91108   U.S.A.

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..TITLE
            Maximal Coverage MIP83 (d=5, p=1)

..OBJECTIVE MAXIMIZE

*state 1
   20 [[x101]] + 22 [[x111]] + 24 [[x121]] + 21 [[x131]]
 + 23 [[x102]] + 19 [[x112]] + 28 [[x122]] + 22 [[x132]]
 + 27 [[x103]] + 23 [[x113]] + 21 [[x123]]   25 [[x133]]

*state 2
 + 21 [[x144]] + 27 [[x154]] + 25 [[x164]] + 21 [[x174]]
 + 21 [[x145]] + 23 [[x155]] + 23 [[x165]] + 23 [[x175]]
 + 19 [[x146]] + 28 [[x156]] + 26 [[x166]] + 26 [[x176]]

*state 3
 + 28 [[x187]] + 24 [[x197]] + 23 [[x207]] + 22 [[x217]]
 + 24 [[x188]] + 23 [[x198]] + 23 [[x208]] + 19 [[x218]]
 + 26 [[x189]] + 22 [[x199]] + 22 [[x209]] + 19 [[x219]]

*state 1 facilities
 + 0 [[y1]] + 0 [[y2]] + 0 [[y3]]
*state 2 facilities
 + 0 [[y4]] + 0 [[y5]] + 0 [[y6]]
*state 3 facilities
 + 0 [[y7]] + 0 [[y8]] + 0 [[y9]]


..CONSTRAINTS

*state 1:  a sat cannot be observed unless a facility is avail

 y1 - x101 >= 0
 y1 - x111 >= 0
 y1 - x121 >= 0
 y1 - x131 >= 0

 y2 - x102 >= 0
```

```
y2 - x112 >= 0
y2 - x122 >= 0
y2 - x132 >= 0

y3 - x103 >= 0
y3 - x113 >= 0
y3 - x123 >= 0
y3 - x133 >= 0

*state 2:  a sat cannot be observed unless a facility is avail

y4 - x144 >= 0
y4 - x154 >= 0
y4 - x164 >= 0
y4 - x174 >= 0

y5 - x145 >= 0
y5 - x155 >= 0
y5 - x165 >= 0
y5 - x175 >= 0


y6 - x146 >= 0
y6 - x156 >= 0
y6 - x166 >= 0
y6 - x176 >= 0


*state 3:  a sat cannot be observed unless a facility is avail

y7 - x187 >= 0
y7 - x197 >= 0
y7 - x207 >= 0
y7 - x217 >= 0

y8 - x188 >= 0
y8 - x198 >= 0
y8 - x208 >= 0
y8 - x218 >= 0

y9 - x189 >= 0
y9 - x199 >= 0
y9 - x209 >= 0
y9 - x219 >= 0


*state 1:  min # of times satellite to be imaged (d=5)
20 x101 + 23 x102 + 27 x103  >= 5
22 x111 + 19 x112 + 23 x113  >= 5
24 x121 + 28 x122 + 21 x123  >= 5
21 x131 + 22 x132 + 25 x133  >= 5
```

```
*state 2:  min # of times satellite to be imaged (d=5)
 21 x144 + 21 x145 + 19 x146  >= 5
 27 x154 + 23 x155 + 28 x156  >= 5
 25 x164 + 23 x165 + 26 x166  >= 5
 21 x174 + 23 x175 + 26 x176  >= 5

*state 3:  min # of times satellite to be imaged (d=5)
 28 x187 + 24 x188 + 26 x189  >= 5
 24 x197 + 23 x198 + 22 x199  >= 5
 23 x207 + 23 x208 + 22 x209  >= 5
 22 x217 + 19 x218 + 19 x219  >= 5


*If facility is in place in one state, must be in other state

 y1 - y4 = 0
 y1 - y7 = 0

 y2 - y5 = 0
 y2 - y8 = 0

 y3 - y6 = 0
 y3 - y9 = 0


*Restriction on the number of facilities (p=1)

 y1 + y2 + y3 = 1

Statistics-
  MIP83 Version 5.00a
  Machine memory:  550K bytes.
  Pagable memory:   95K bytes.
  Objective Function is MAXIMIZED.
  MIP Strategy:       1
  Variables:         45
    Integer:         45
  Constraints:       55
     0 LE,    7 EQ,  48 GE.
  Non-zero LP elements:      123
  Disk Space:      0K bytes.
  Page Space:     25K bytes.
  Capacity: 12.7% used.
  Estimated Time: 00:00:17

Iter   92
Solution Time:  00:00:02
*May have* A L T E R N A T E   S O L U T I O N

INTEGER SOLUTION
```

File: Maxproj 9/12/92 20:42:31 Page 1-1

SOLUTION (Maximized): 284.0000 Maximal Coverage MIP83 (d=5, p=1)

Variable	Activity	Cost	Variable	Activity	Cost
x101	0.0000	20.0000	x111	0.0000	22.0000
x121	0.0000	24.0000	x131	0.0000	21.0000
x102	0.0000	23.0000	x112	0.0000	19.0000
x122	0.0000	28.0000	x132	0.0000	22.0000
x103	1.0000	27.0000	x113	1.0000	23.0000
x123	1.0000	21.0000	x133	1.0000	25.0000
x144	0.0000	21.0000	x154	0.0000	27.0000
x164	0.0000	25.0000	x174	0.0000	21.0000
x145	0.0000	21.0000	x155	0.0000	23.0000
x165	0.0000	23.0000	x175	0.0000	23.0000
x146	1.0000	19.0000	x156	1.0000	28.0000
x166	1.0000	26.0000	x176	1.0000	26.0000
x187	0.0000	28.0000	x197	0.0000	24.0000
x207	0.0000	23.0000	x217	0.0000	22.0000
x188	0.0000	24.0000	x198	0.0000	23.0000
x208	0.0000	23.0000	x218	0.0000	19.0000
x189	1.0000	26.0000	x199	1.0000	22.0000
x209	1.0000	22.0000	x219	1.0000	19.0000
y1	0.0000	0.0000	y2	0.0000	0.0000
y3	1.0000	0.0000	y4	0.0000	0.0000
y5	0.0000	0.0000	y6	1.0000	0.0000
y7	0.0000	0.0000	y8	0.0000	0.0000
y9	1.0000	0.0000			

CONSTRAINTS: Maximal Coverage MIP83 (d=5, p=1)

Constraint	Activity		RHS	Constraint	Activity		RHS
Row 1	0.0000	>	0.0000	Row 2	0.0000	>	0.0000
Row 3	0.0000	>	0.0000	Row 4	0.0000	>	0.0000
Row 5	0.0000	>	0.0000	Row 6	0.0000	>	0.0000
Row 7	0.0000	>	0.0000	Row 8	0.0000	>	0.0000
Row 9	0.0000	>	0.0000	Row 10	0.0000	>	0.0000
Row 11	0.0000	>	0.0000	Row 12	0.0000	>	0.0000
Row 13	0.0000	>	0.0000	Row 14	0.0000	>	0.0000
Row 15	0.0000	>	0.0000	Row 16	0.0000	>	0.0000
Row 17	0.0000	>	0.0000	Row 18	0.0000	>	0.0000
Row 19	0.0000	>	0.0000	Row 20	0.0000	>	0.0000
Row 21	0.0000	>	0.0000	Row 22	0.0000	>	0.0000
Row 23	0.0000	>	0.0000	Row 24	0.0000	>	0.0000
Row 25	0.0000	>	0.0000	Row 26	0.0000	>	0.0000
Row 27	0.0000	>	0.0000	Row 28	0.0000	>	0.0000
Row 29	0.0000	>	0.0000	Row 30	0.0000	>	0.0000
Row 31	0.0000	>	0.0000	Row 32	0.0000	>	0.0000
Row 33	0.0000	>	0.0000	Row 34	0.0000	>	0.0000
Row 35	0.0000	>	0.0000	Row 36	0.0000	>	0.0000
Row 37	27.0000	>	5.0000	Row 38	23.0000	>	5.0000
Row 39	21.0000	>	5.0000	Row 40	25.0000	>	5.0000
Row 41	19.0000	>	5.0000	Row 42	28.0000	>	5.0000
Row 43	26.0000	>	5.0000	Row 44	26.0000	>	5.0000
Row 45	26.0000	>	5.0000	Row 46	22.0000	>	5.0000
Row 47	22.0000	>	5.0000	Row 48	19.0000	>	5.0000
Row 49	0.0000	=	0.0000	Row 50	0.0000	=	0.0000
Row 51	0.0000	=	0.0000	Row 52	0.0000	=	0.0000

Row	53	0.0000 =	0.0000	Row	54	0.0000 =	0.0000
Row	55	1.0000 =	1.0000				

Total Error: 0.000000

Appendix D. *MICROSOLVE Network Solution* ($p = 1$)

PRIMAL SIMPLEX ALGORITHM

OPTIMUM SOLUTION OBTAINED.

ARC PARAMETERS AND FLOWS
SOLUTION COST = -300.9948

ARCS THAT START AT 1

GO TO	ARC NO.	LOWER	UPPER	COST	GAIN	FLOW
10	1	0	1	-20	1	0
11	2	0	1	-22	1	0
12	3	0	1	-24	1	0
4	4	0	1	0	5	.4
13	5	0	1	-21	1	0

ARCS THAT START AT 2

GO TO	ARC NO.	LOWER	UPPER	COST	GAIN	FLOW
10	6	0	1	-23	1	0
11	7	0	1	-19	1	0
12	8	0	1	-28	1	1
13	9	0	1	-22	1	0
5	10	0	1	0	5	0

ARCS THAT START AT 3

GO TO	ARC NO.	LOWER	UPPER	COST	GAIN	FLOW
10	11	0	1	-27	1	1
11	12	0	1	-23	1	1
12	13	0	1	-21	1	0
13	14	0	1	-25	1	1
6	15	0	1	0	5	.6

ARCS THAT START AT 4

GO TO	ARC NO.	LOWER	UPPER	COST	GAIN	FLOW
14	16	0	1	-21	1	1
15	17	0	1	-27	1	0
16	18	0	1	-25	1	0
17	19	0	1	-21	1	0
7	20	0	1	0	4	1

ARCS THAT START AT 5

GO TO	ARC NO.	LOWER	UPPER	COST	GAIN	FLOW
14	21	0	1	-21	1	0
15	22	0	1	-23	1	0
16	23	0	1	-23	1	0
17	24	0	1	-23	1	0
8	25	0	1	0	4	0

ARCS THAT START AT 6

GO TO	ARC NO.	LOWER	UPPER	COST	GAIN	FLOW
14	26	0	1	-19	1	0
15	27	0	1	-28	1	1
16	28	0	1	-26	1	1
17	29	0	1	-26	1	1
9	30	0	1	0	4	0

ARCS THAT START AT 7

GO TO	ARC NO.	LOWER	UPPER	COST	GAIN	FLOW
18	31	0	1	-28	1	1
19	32	0	1	-24	1	1
20	33	0	1	-23	1	1
21	34	0	1	-22	1	1

ARCS THAT START AT 8

GO TO	ARC NO.	LOWER	UPPER	COST	GAIN	FLOW
18	35	0	1	-24	1	0
19	36	0	1	-23	1	0
20	37	0	1	-23	1	0
21	38	0	1	-19	1	0

ARCS THAT START AT 9

GO TO	ARC NO.	LOWER	UPPER	COST	GAIN	FLOW
18	39	0	1	-26	1	0
19	40	0	1	-22	1	0
20	41	0	1	-22	1	0
21	42	0	1	-19	1	0

ARCS THAT START AT 10

GO TO	ARC NO.	LOWER	UPPER	COST	GAIN	FLOW

------	------	------	------	------	------	------
t	43	0	1	0	1	1

ARCS THAT START AT 11

GO TO	ARC NO.	LOWER	UPPER	COST	GAIN	FLOW
t	44	0	1	0	1	1

ARCS THAT START AT 12

GO TO	ARC NO.	LOWER	UPPER	COST	GAIN	FLOW
t	45	0	1	0	1	1

ARCS THAT START AT 13

GO TO	ARC NO.	LOWER	UPPER	COST	GAIN	FLOW
t	46	0	1	0	1	1

ARCS THAT START AT 14

GO TO	ARC NO.	LOWER	UPPER	COST	GAIN	FLOW
t	47	0	1	0	1	1

ARCS THAT START AT 15

GO TO	ARC NO.	LOWER	UPPER	COST	GAIN	FLOW
t	48	0	1	0	1	1

ARCS THAT START AT 16

GO TO	ARC NO.	LOWER	UPPER	COST	GAIN	FLOW
t	49	0	1	0	1	1

ARCS THAT START AT 17

GO TO	ARC NO.	LOWER	UPPER	COST	GAIN	FLOW
t	50	0	1	0	1	1

ARCS THAT START AT 18

GO TO	ARC NO.	LOWER	UPPER	COST	GAIN	FLOW
t	51	0	1	0	1	1

ARCS THAT START AT 19

GO TO	ARC NO.	LOWER	UPPER	COST	GAIN	FLOW
t	52	0	1	0	1	1

ARCS THAT START AT 20

GO TO	ARC NO.	LOWER	UPPER	COST	GAIN	FLOW
t	53	0	1	0	1	1

ARCS THAT START AT 21

GO TO	ARC NO.	LOWER	UPPER	COST	GAIN	FLOW
t	54	0	1	0	1	1

ARCS THAT START AT s

GO TO	ARC NO.	LOWER	UPPER	COST	GAIN	FLOW
1	55	0	1	0	5	.08
2	56	0	1	0	5	.2
3	57	0	1	0	5	.72
SLACK	58	0	1	99999	1	5.21E-08

NO ARCS START AT NODE t

ARCS THAT START AT SLACK

GO TO	ARC NO.	LOWER	UPPER	COST	GAIN	FLOW
1	59	0	0	99999	1	0
2	60	0	0	99999	1	0
3	61	0	0	99999	1	0
4	62	0	0	99999	1	0
5	63	0	0	99999	1	0
6	64	0	0	99999	1	0
7	65	0	0	99999	1	0
8	66	0	0	99999	1	0
9	67	0	0	99999	1	0
10	68	0	0	99999	1	0
11	69	0	0	99999	1	0
12	70	0	0	99999	1	0
13	71	0	0	99999	1	0
14	72	0	0	99999	1	0
15	73	0	0	99999	1	0
16	74	0	0	99999	1	0
17	75	0	0	99999	1	0
18	76	0	0	99999	1	0

19	77	0	0	99999	1	0
20	78	0	0	99999	1	0
21	79	0	0	99999	1	0
t	80	0	12	99999	1	0

NODE PARAMETERS

NODE	NAME	POTENTIAL	EXT.FLOW
1	1	-19999.8	0
2	2	-19999.8	0
3	3	-19999.8	0
4	4	-3999.96	0
5	5	-3999.96	0
6	6	-3999.96	0
7	7	-999.9901	0
8	8	-999.9901	0
9	9	-999.9901	0
10	10	-20022.8	0
11	11	-20021.8	0
12	12	-20023.8	0
13	13	-20021.8	0
14	14	-4020.96	0
15	15	-4026.96	0
16	16	-4024.96	0
17	17	-4022.96	0
18	18	-1025.99	0
19	19	-1022.99	0
20	20	-1022.99	0
21	21	-1018.99	0
22	s	-99999	1
23	t	99999	-12
24	SLACK	0	0

BASIS TREE

NODE NAME	BACK ARC	BACK NODE	FORWARD NODE	RIGHT NODE
1	55	s	11	
2	56	s	13	3
3	57	s	6	1
4	4	1	15	
5	10	2	17	
6	15	3	9	
7	20	4		
8	25	5	20	
9	30	6	18	
10	6	2		5
11	2	1		12

12	3	1		4
13	9	2		10
14	21	5		8
15	17	4		16
16	18	4		7
17	24	5		14
18	39	9		
19	36	8		
20	37	8		21
21	38	8		19
s	-58	SLACK	2	
t	80	SLACK		s
SLACK	0		t	

Appendix E. *Network With Side Constraints-Formulation 1*

E.1 Formulation

```
options linesize=120;
options pagesize=66;
title 'Facility Location - run 1';
title3 'Nodes for Facility Location';
   data noded;
      input _node_ $ _sd_;
      cards;
   s 0
   t 0
;

title3 'Arcs for Facility Location';
   data arcd1;
      input _from_ $ _to_ $ _cost_ _capac_ _name_ $;
      cards;
   s   n1  0  1  xs1
   s   n2  0  1  xs2
   s   n3  0  1  xs3
   n1  n10 20 1  x110
   n1  n11 22 1  x111
   n1  n12 24 1  x112
   n1  n13 21 1  x113
   n1  n4  0  1  x14
   n2  n10 23 1  x210
   n2  n11 19 1  x211
   n2  n12 28 1  x212
   n2  n13 22 1  x213
   n2  n5  0  1  x25
   n3  n10 27 1  x310
   n3  n11 23 1  x311
   n3  n12 21 1  x312
   n3  n13 25 1  x313
   n3  n6  0  1  x36
   n4  n14 21 1  x414
   n4  n15 27 1  x415
   n4  n16 25 1  x416
   n4  n17 21 1  x417
   n4  n7  0  1  x47
   n5  n14 21 1  x514
   n5  n15 23 1  x515
   n5  n16 23 1  x516
   n5  n17 23 1  x517
   n5  n8  0  1  x58
   n6  n14 19 1  x614
```

```
    n6  n15 28 1  x615
    n6  n16 26 1  x616
    n6  n17 26 1  x617
    n6  n9  0  1  x69
    n7  n18 28 1  x718
    n7  n19 24 1  x719
    n7  n20 23 1  x720
    n7  n21 22 1  x721
    n8  n18 24 1  x818
    n8  n19 23 1  x819
    n8  n20 23 1  x820
    n8  n21 19 1  x821
    n9  n18 26 1  x918
    n9  n19 22 1  x919
    n9  n20 22 1  x920
    n9  n21 19 1  x921
    n10 t   0  1  x10t
    n11 t   0  1  x11t
    n12 t   0  1  x12t
    n13 t   0  1  x13t
    n14 t   0  1  x14t
    n15 t   0  1  x15t
    n16 t   0  1  x16t
    n17 t   0  1  x17t
    n18 t   0  1  x18t
    n19 t   0  1  x19t
    n20 t   0  1  x20t
    n21 t   0  1  x21t
    t   s   0  .  xts
;

title3 'Side constraints';
data cond1;
   input xs1 xs2 xs3 x110 x111 x112 x113 x14 x210 x211 x212 x213 x25
   x310 x311 x312 x313 x36 x414 x415 x416 x417 x47 x514 x515 x516 x517 x58
   x614 x615 x616 x617 x69 x718 x719 x720 x721 x818 x819 x820 x821
   x918 x919 x920 x921 _type_ $ _rhs_;
   cards;

-5 . . 1 1 1 1 1 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. -5 . . . . . . 1 1 1 1 1 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . -5 . . . . . . . . . . 1 1 1 1 1 . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . . . . . . -5 . . . . . . . . . . 1 1 1 1 1 . . . . . . . . . . . . . . . . . . . . . . = 0
. . . . . . . . . . . . -5 . . . . . . . . . . 1 1 1 1 1 . . . . . . . . . . . . . . . . . = 0
. . . . . . . . . . . . . . . . . -5 . . . . . . . . . . 1 1 1 1 1 . . . . . . . . . . . . = 0
. . . . . . . . . . . . . . . . . . . . . . -4 . . . . . . . . . . 1 1 1 1 . . . . . . . . = 0
. . . . . . . . . . . . . . . . . . . . . . . . . . . -4 . . . . . . . . . 1 1 1 1 . . . . = 0
. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . -4 . . . . . . . . 1 1 1 1 = 0
;

proc netflow
  nodedata=noded
  arcdata=arcd1
```

```
  condata=cond1
  conout=solution
  max
  sourcenode=s
  sinknode=t
  namectrl=1;

proc print data=solution;
sum _fcost_;
```

E.2 Solution

OBS	_FROM_	_TO_	_COST_	_CAPAC_	_LO_	_NAME_	SUPPLY	DEMAND	_FLOW_	_FCOST_	_RCOST_	_ANUMB_	_TNUMB_	_STATUS_
1	s	n1	0	1	0	XS1	S	.	0	0	.	2	1	KEY_ARC BASIC
2	n1	n10	20	1	0	X110	.	.	0	0	-9.0	5	2	LOWERBD NONBASIC
3	n2	n10	23	1	0	X210	.	.	0	0	-4.0	6	3	LOWERBD NONBASIC
4	n3	n10	27	1	0	X310	.	.	0	0	.	7	4	KEY_ARC BASIC
5	n1	n11	22	1	0	X111	.	.	0	0	-3.0	8	2	LOWERBD NONBASIC
6	n2	n11	19	1	0	X211	.	.	0	0	-4.0	9	3	LOWERBD NONBASIC
7	n3	n11	23	1	0	X311	.	.	0	0	.	10	4	KEY_ARC BASIC
8	n1	n12	24	1	0	X112	.	.	0	0	-49999975.5	11	2	LOWERBD NONBASIC
9	n2	n12	28	1	0	X212	.	.	0	0	-49999969.5	12	3	LOWERBD NONBASIC
10	n3	n12	21	1	0	X312	.	.	0	0	-49999976.5	13	4	LOWERBD NONBASIC
11	n1	n13	21	1	0	X113	.	.	0	0	-6.0	14	2	LOWERBD NONBASIC
12	n2	n13	22	1	0	X213	.	.	0	0	-3.0	15	3	LOWERBD NONBASIC
13	n3	n13	25	1	0	X313	.	.	0	0	.	16	4	KEY_ARC BASIC
14	n4	n14	21	1	0	X414	.	.	0	0	-2.0	20	9	LOWERBD NONBASIC
15	n5	n14	21	1	0	X514	.	.	0	0	.	21	10	KEY_ARC BASIC
16	n6	n14	19	1	0	X614	.	.	0	0	-2.0	22	11	LOWERBD NONBASIC
17	n4	n15	27	1	0	X415	.	.	0	0	-99999972.0	23	9	LOWERBD NONBASIC
18	n5	n15	23	1	0	X515	.	.	0	0	-99999974.0	24	10	LOWERBD NONBASIC
19	n6	n15	28	1	0	X615	.	.	0	0	-99999969.0	25	11	LOWERBD NONBASIC
20	n4	n16	25	1	0	X416	.	.	0	0	-3.0	26	9	LOWERBD NONBASIC
21	n5	n16	23	1	0	X516	.	.	0	0	-3.0	27	10	LOWERBD NONBASIC
22	n6	n16	26	1	0	X616	.	.	0	0	.	28	11	KEY_ARC BASIC
23	n4	n17	21	1	0	X417	.	.	0	0	-7.0	29	9	LOWERBD NONBASIC
24	n5	n17	23	1	0	X517	.	.	0	0	-3.0	30	10	LOWERBD NONBASIC
25	n6	n17	26	1	0	X617	.	.	0	0	.	31	11	KEY_ARC BASIC
26	n7	n18	28	1	0	X718	.	.	0	0	.	35	16	KEY_ARC BASIC
27	n8	n18	24	1	0	X818	.	.	0	0	-2.0	36	17	LOWERBD NONBASIC
28	n9	n18	26	1	0	X918	.	.	0	0	.	37	18	KEY_ARC BASIC
29	n7	n19	24	1	0	X719	.	.	0	0	-1.0	38	16	LOWERBD NONBASIC
30	n8	n19	23	1	0	X819	.	.	0	0	.	39	17	KEY_ARC BASIC
31	n9	n19	22	1	0	X919	.	.	0	0	-1.0	40	18	LOWERBD NONBASIC
32	s	n2	0	1	0	XS2	S	.	0	0	-2.0	3	1	LOWERBD NONBASIC
33	n7	n20	23	1	0	X720	.	.	0	0	-2.0	41	16	LOWERBD NONBASIC
34	n8	n20	23	1	0	X820	.	.	0	0	.	42	17	KEY_ARC BASIC
35	n9	n20	22	1	0	X920	.	.	0	0	-1.0	43	18	LOWERBD NONBASIC
36	n7	n21	22	1	0	X721	.	.	0	0	.	44	16	KEY_ARC BASIC
37	n8	n21	19	1	0	X821	.	.	0	0	-1.0	45	17	LOWERBD NONBASIC
38	n9	n21	19	1	0	X921	.	.	0	0	-1.0	46	18	LOWERBD NONBASIC
39	s	n3	0	1	0	XS3	S	.	0	0	-2.0	4	1	LOWERBD NONBASIC
40	n1	n4	0	1	0	X14	.	.	0	0	.	17	2	KEY_ARC BASIC
41	n2	n5	0	1	0	X25	.	.	0	0	.	18	3	KEY_ARC BASIC
42	n3	n6	0	1	0	X36	.	.	0	0	.	19	4	KEY_ARC BASIC
43	n4	n7	0	1	0	X47	.	.	0	0	.	32	9	KEY_ARC BASIC
44	n5	n8	0	1	0	X58	.	.	0	0	.	33	10	KEY_ARC BASIC
45	n6	n9	0	1	0	X69	.	.	0	0	.	34	11	KEY_ARC BASIC
46	t	s	0	99999999	0	XTS	.	.	0	0	.	1	23	KEY_ARC BASIC
47	n10	t	0	1	0	X10T	.	D	0	0	-49999970.5	47	5	LOWERBD NONBASIC
48	n11	t	0	1	0	X11T	.	D	0	0	-49999974.5	48	6	LOWERBD NONBASIC
49	n12	t	0	1	0	X12T	.	D	0	0	.	49	7	KEY_ARC BASIC
50	n13	t	0	1	0	X13T	.	D	0	0	-49999972.5	50	8	LOWERBD NONBASIC
51	n14	t	0	1	0	X14T	.	D	0	0	-99999976.0	51	12	LOWERBD NONBASIC
52	n15	t	0	1	0	X15T	.	D	0	0	.	52	13	KEY_ARC BASIC
53	n16	t	0	1	0	X16T	.	D	0	0	-99999971.0	53	14	LOWERBD NONBASIC
54	n17	t	0	1	0	X17T	.	D	0	0	-99999971.0	54	15	LOWERBD NONBASIC
55	n18	t	0	1	0	X18T	.	D	0	0	-174999970.3	55	19	LOWERBD NONBASIC
56	n19	t	0	1	0	X19T	.	D	0	0	-174999973.3	56	20	LOWERBD NONBASIC

57	n20	t	0	1	0	X20T	.	D	0	0	-174999973.3	57	21	LOWERBD NONBASIC
58	n21	t	0	1	0	X21T	.	D	0	0	-174999976.3	58	22	LOWERBD NONBASIC
										=				
										0				

Appendix F. *Network With Side Constraints–Formulation 2*

F.1 Formulation

```
options linesize=120;
options pagesize=66;
title 'Facility Location - run 2';
title3 'Nodes for Facility Location';
   data noded;
      input _node_ $ _sd_;
      cards;
   s 0
   t 0
;

title3 'Arcs for Facility Location';
   data arcd1;
      input _from_ $ _to_ $ _cost_ _capac_ _name_ $;
      cards;
   s   n1  0  5  xs1
   s   n2  0  5  xs2
   s   n3  0  5  xs3
   n1  n10 20 1  x110
   n1  n11 22 1  x111
   n1  n12 24 1  x112
   n1  n13 21 1  x113
   n1  n4  0  5  x14
   n2  n10 23 1  x210
   n2  n11 19 1  x211
   n2  n12 28 1  x212
   n2  n13 22 1  x213
   n2  n5  0  5  x25
   n3  n10 27 1  x310
   n3  n11 23 1  x311
   n3  n12 21 1  x312
   n3  n13 25 1  x313
   n3  n6  0  5  x36
   n4  n14 21 1  x414
   n4  n15 27 1  x415
   n4  n16 25 1  x416
   n4  n17 21 1  x417
   n4  n7  0  4  x47
   n5  n14 21 1  x514
   n5  n15 23 1  x515
   n5  n16 23 1  x516
   n5  n17 23 1  x517
   n5  n8  0  4  x58
   n6  n14 19 1  x614
   n6  n15 28 1  x615
```

```
   n6  n16 26 1  x616
   n6  n17 26 1  x617
   n6  n9  0  4  x69
   n7  n18 28 1  x718
   n7  n19 24 1  x719
   n7  n20 23 1  x720
   n7  n21 22 1  x721
   n8  n18 24 1  x818
   n8  n19 23 1  x819
   n8  n20 23 1  x820
   n8  n21 19 1  x821
   n9  n18 26 1  x918
   n9  n19 22 1  x919
   n9  n20 22 1  x920
   n9  n21 19 1  x921
   n10 t   0  1  x10t
   n11 t   0  1  x11t
   n12 t   0  1  x12t
   n13 t   0  1  x13t
   n14 t   0  1  x14t
   n15 t   0  1  x15t
   n16 t   0  1  x16t
   n17 t   0  1  x17t
   n18 t   0  1  x18t
   n19 t   0  1  x19t
   n20 t   0  1  x20t
   n21 t   0  1  x21t
   t   s   0  .  xts
;

title3 'Side constraints';
data cond1;
   input xs1 xs2 xs3 x110 x111 x112 x113 x14 x210 x211 x212 x213 x25
   x310 x311 x312 x313 x36 x414 x415 x416 x417 x47 x514 x515 x516 x517 x58
   x614 x615 x616 x617 x69 x718 x719 x720 x721 x818 x819 x820 x821
   x918 x919 x920 x921 _type_ $ _rhs_;
   cards;

-1 . . 1 1 1 1 1 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. -1 . . . . . . 1 1 1 1 1 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . -1 . . . . . . . . . . 1 1 1 1 1 . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . . . . . . -1 . . . . . . . . . . 1 1 1 1 1 . . . . . . . . . . . . . . . . . . . . . . = 0
. . . . . . . . . . . . -1 . . . . . . . . . . 1 1 1 1 1 . . . . . . . . . . . . . . . . . = 0
. . . . . . . . . . . . . . . . . -1 . . . . . . . . . . 1 1 1 1 1 . . . . . . . . . . . . = 0
. . . . . . . . . . . . . . . . . . . . . . -1 . . . . . . . . . . 1 1 1 1 . . . . . . . . = 0
. . . . . . . . . . . . . . . . . . . . . . . . . . . -1 . . . . . . . . . 1 1 1 1 . . . . = 0
. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . -1 . . . . . . . . 1 1 1 1 = 0
;


proc netflow
  nodedata=noded
  arcdata=arcd1
```

```
  condata=cond1
  conout=solution
  max
  sourcenode=s
  sinknode=t
  namectrl=1;

proc print data=solution;
sum _fcost_;
```

F.2 Solution

OBS	_FROM_	_TO_	_COST_	_CAPAC_	_LO_	_NAME_	_SUPPLY_	_DEMAND_	_FLOW_	_FCOST_	_RCOST_	_ANUMB_	_TNUMB_	_STATUS_
1	s	n1	0	5	0	XS1	S	.	5	0	0	2	1	UPPERBD NONBASIC
2	n1	n10	20	1	0	X110	.	.	0	0	-6	5	2	LOWERBD NONBASIC
3	n2	n10	23	1	0	X210	.	.	0	0	-3	6	3	LOWERBD NONBASIC
4	n3	n10	27	1	0	X310	.	.	1	27	.	7	4	KEY_ARC BASIC
5	n1	n11	22	1	0	X111	.	.	1	22	0	8	2	UPPERBD NONBASIC
6	n2	n11	19	1	0	X211	.	.	0	0	-3	9	3	LOWERBD NONBASIC
7	n3	n11	23	1	0	X311	.	.	0	0	.	10	4	KEY_ARC BASIC
8	n1	n12	24	1	0	X112	.	.	0	0	-4	11	2	LOWERBD NONBASIC
9	n2	n12	28	1	0	X212	.	.	1	28	.	12	3	KEY_ARC BASIC
10	n3	n12	21	1	0	X312	.	.	0	0	-8	13	4	LOWERBD NONBASIC
11	n1	n13	21	1	0	X113	.	.	0	0	-3	14	2	LOWERBD NONBASIC
12	n2	n13	22	1	0	X213	.	.	0	0	-2	15	3	LOWERBD NONBASIC
13	n3	n13	25	1	0	X313	.	.	1	25	.	16	4	KEY_ARC BASIC
14	n4	n14	21	1	0	X414	.	.	0	0	.	20	9	KEY_ARC BASIC
15	n5	n14	21	1	0	X514	.	.	1	21	0	21	10	UPPERBD NONBASIC
16	n6	n14	19	1	0	X614	.	.	0	0	-3	22	11	LOWERBD NONBASIC
17	n4	n15	27	1	0	X415	.	.	0	0	.	23	9	KEY_ARC BASIC
18	n5	n15	23	1	0	X515	.	.	0	0	-4	24	10	LOWERBD NONBASIC
19	n6	n15	28	1	0	X615	.	.	1	28	.	25	11	KEY_ARC BASIC
20	n4	n16	25	1	0	X416	.	.	0	0	0	26	9	LOWERBD NONBASIC
21	n5	n16	23	1	0	X516	.	.	0	0	-2	27	10	LOWERBD NONBASIC
22	n6	n16	26	1	0	X616	.	.	1	26	.	28	11	KEY_ARC BASIC
23	n4	n17	21	1	0	X417	.	.	0	0	-4	29	9	LOWERBD NONBASIC
24	n5	n17	23	1	0	X517	.	.	0	0	-2	30	10	LOWERBD NONBASIC
25	n6	n17	26	1	0	X617	.	.	1	26	.	31	11	KEY_ARC BASIC
26	n7	n18	28	1	0	X718	.	.	1	28	.	35	16	KEY_ARC BASIC
27	n8	n18	24	1	0	X818	.	.	0	0	-4	36	17	LOWERBD NONBASIC
28	n9	n18	26	1	0	X918	.	.	0	0	-2	37	18	LOWERBD NONBASIC
29	n7	n19	24	1	0	X719	.	.	1	24	.	38	16	KEY_ARC BASIC
30	n8	n19	23	1	0	X819	.	.	0	0	-1	39	17	LOWERBD NONBASIC
31	n9	n19	22	1	0	X919	.	.	0	0	-2	40	18	LOWERBD NONBASIC
32	s	n2	0	5	0	XS2	S	.	2	0	.	3	1	KEY_ARC BASIC
33	n7	n20	23	1	0	X720	.	.	1	23	.	41	16	KEY_ARC BASIC
34	n8	n20	23	1	0	X820	.	.	0	0	.	42	17	KEY_ARC BASIC
35	n9	n20	22	1	0	X920	.	.	0	0	-1	43	18	LOWERBD NONBASIC
36	n7	n21	22	1	0	X721	.	.	1	22	.	44	16	KEY_ARC BASIC
37	n8	n21	19	1	0	X821	.	.	0	0	-3	45	17	LOWERBD NONBASIC
38	n9	n21	19	1	0	X921	.	.	0	0	-3	46	18	LOWERBD NONBASIC
39	s	n3	0	5	0	XS3	S	.	5	0	1	4	1	UPPERBD NONBASIC
40	n1	n4	0	5	0	X14	.	.	4	0	.	17	2	KEY_ARC BASIC
41	n2	n5	0	5	0	X25	.	.	1	0	.	18	3	KEY_ARC BASIC
42	n3	n6	0	5	0	X36	.	.	3	0	.	19	4	KEY_ARC BASIC
43	n4	n7	0	4	0	X47	.	.	4	0	.	32	9	KEY_ARC BASIC
44	n5	n8	0	4	0	X58	.	.	0	0	.	33	10	KEY_ARC BASIC
45	n6	n9	0	4	0	X69	.	.	0	0	-1	34	11	LOWERBD NONBASIC
46	t	s	0	99999999	0	XTS	.	.	12	0	.	1	23	KEY_ARC BASIC
47	n10	t	0	1	0	X10T	.	D	1	0	26	47	5	UPPERBD NONBASIC
48	n11	t	0	1	0	X11T	.	D	1	0	22	48	6	UPPERBD NONBASIC
49	n12	t	0	1	0	X12T	.	D	1	0	28	49	7	UPPERBD NONBASIC
50	n13	t	0	1	0	X13T	.	D	1	0	24	50	8	UPPERBD NONBASIC
51	n14	t	0	1	0	X14T	.	D	1	0	21	51	12	UPPERBD NONBASIC
52	n15	t	0	1	0	X15T	.	D	1	0	27	52	13	UPPERBD NONBASIC
53	n16	t	0	1	0	X16T	.	D	1	0	25	53	14	UPPERBD NONBASIC
54	n17	t	0	1	0	X17T	.	D	1	0	25	54	15	UPPERBD NONBASIC
55	n18	t	0	1	0	X18T	.	D	1	0	28	55	19	UPPERBD NONBASIC
56	n19	t	0	1	0	X19T	.	D	1	0	24	56	20	UPPERBD NONBASIC
57	n20	t	0	1	0	X20T	.	D	1	0	23	57	21	UPPERBD NONBASIC
58	n21	t	0	1	0	X21T	.	D	1	0	22	58	22	UPPERBD NONBASIC
										=======				
										300				

Appendix G. *Network With Side Constraints–Formulation 3*

G.1 Formulation

```
options linesize=120;
options pagesize=66;
title 'Facility Location - run 3';
title3 'Nodes for Facility Location';
   data noded;
      input _node_ $ _sd_;
      cards;
   s 0
   t 0
;

title3 'Arcs for Facility Location';
   data arcd1;
      input _from_ $ _to_ $ _cost_ _capac_ _name_ $;
      cards;
   s   n1  0  12 xs1
   s   n2  0  12 xs2
   s   n3  0  12 xs3
   n1  n10 20 1  x110
   n1  n11 22 1  x111
   n1  n12 24 1  x112
   n1  n13 21 1  x113
   n1  n4  0  8  x14
   n2  n10 23 1  x210
   n2  n11 19 1  x211
   n2  n12 28 1  x212
   n2  n13 22 1  x213
   n2  n5  0  8  x25
   n3  n10 27 1  x310
   n3  n11 23 1  x311
   n3  n12 21 1  x312
   n3  n13 25 1  x313
   n3  n6  0  8  x36
   n4  n14 21 1  x414
   n4  n15 27 1  x415
   n4  n16 25 1  x416
   n4  n17 21 1  x417
   n4  n7  0  4  x47
   n5  n14 21 1  x514
   n5  n15 23 1  x515
   n5  n16 23 1  x516
   n5  n17 23 1  x517
   n5  n8  0  4  x58
   n6  n14 19 1  x614
```

```
   n6   n15 28 1   x615
   n6   n16 26 1   x616
   n6   n17 26 1   x617
   n6   n9  0  4   x69
   n7   n18 28 1   x718
   n7   n19 24 1   x719
   n7   n20 23 1   x720
   n7   n21 22 1   x721
   n8   n18 24 1   x818
   n8   n19 23 1   x819
   n8   n20 23 1   x820
   n8   n21 19 1   x821
   n9   n18 26 1   x918
   n9   n19 22 1   x919
   n9   n20 22 1   x920
   n9   n21 19 1   x921
   n10 t    0  1   x10t
   n11 t    0  1   x11t
   n12 t    0  1   x12t
   n13 t    0  1   x13t
   n14 t    0  1   x14t
   n15 t    0  1   x15t
   n16 t    0  1   x16t
   n17 t    0  1   x17t
   n18 t    0  1   x18t
   n19 t    0  1   x19t
   n20 t    0  1   x20t
   n21 t    0  1   x21t
   t    s    0  .   xts
;

title3 'Side constraints';
data cond1;
   input xs1 xs2 xs3 x110 x111 x112 x113 x14 x210 x211 x212 x213 x25
   x310 x311 x312 x313 x36 x414 x415 x416 x417 x47 x514 x515 x516 x517 x58
   x614 x615 x616 x617 x69 x718 x719 x720 x721 x818 x819 x820 x821
   x918 x919 x920 x921 _type_ $ _rhs_;
   cards;

-1 . . 1 1 1 1 1 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. -1 . . . . . . 1 1 1 1 1 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . -1 . . . . . . . . . . 1 1 1 1 1 . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . . . . . . -1 . . . . . . . . . . 1 1 1 1 1 . . . . . . . . . . . . . . . . . . . . . . = 0
. . . . . . . . . . . . -1 . . . . . . . . . . 1 1 1 1 1 . . . . . . . . . . . . . . . . . = 0
. . . . . . . . . . . . . . . . . -1 . . . . . . . . . . 1 1 1 1 1 . . . . . . . . . . . . = 0
. . . . . . . . . . . . . . . . . . . . . . -1 . . . . . . . . . . 1 1 1 1 . . . . . . . . = 0
. . . . . . . . . . . . . . . . . . . . . . . . . . . -1 . . . . . . . . . 1 1 1 1 . . . . = 0
. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . -1 . . . . . . . . 1 1 1 1 = 0
;


proc netflow
  nodedata=noded
```

```
  arcdata=arcd1
  condata=cond1
  conout=solution
  max
  sourcenode=s
  sinknode=t
  namectrl=1;

proc print data=solution;
sum _fcost_;
```

G.2 Solution

OBS	_FROM_	_TO_	_COST_	_CAPAC_	_LO_	_NAME_	_SUPPLY_	_DEMAND_	_FLOW_	_FCOST_	_RCOST_	_ANUMB_	_TNUMB_	_STATUS_
1	s	n1	0	12	0	XS1	S	.	5	0	.	2	1	KEY_ARC BASIC
2	n1	n10	20	1	0	X110	.	.	0	0	-7	5	2	LOWERBD NONBASIC
3	n2	n10	23	1	0	X210	.	.	0	0	-4	6	3	LOWERBD NONBASIC
4	n3	n10	27	1	0	X310	.	.	1	27	.	7	4	KEY_ARC BASIC
5	n1	n11	22	1	0	X111	.	.	0	0	-1	8	2	LOWERBD NONBASIC
6	n2	n11	19	1	0	X211	.	.	0	0	-4	9	3	LOWERBD NONBASIC
7	n3	n11	23	1	0	X311	.	.	1	23	.	10	4	KEY_ARC BASIC
8	n1	n12	24	1	0	X112	.	.	0	0	-4	11	2	LOWERBD NONBASIC
9	n2	n12	28	1	0	X212	.	.	1	28	.	12	3	KEY_ARC BASIC
10	n3	n12	21	1	0	X312	.	.	0	0	-7	13	4	LOWERBD NONBASIC
11	n1	n13	21	1	0	X113	.	.	0	0	-4	14	2	LOWERBD NONBASIC
12	n2	n13	22	1	0	X213	.	.	0	0	-3	15	3	LOWERBD NONBASIC
13	n3	n13	25	1	0	X313	.	.	1	25	.	16	4	KEY_ARC BASIC
14	n4	n14	21	1	0	X414	.	.	1	21	.	20	9	KEY_ARC BASIC
15	n5	n14	21	1	0	X514	.	.	0	0	0	21	10	LOWERBD NONBASIC
16	n6	n14	19	1	0	X614	.	.	0	0	-2	22	11	LOWERBD NONBASIC
17	n4	n15	27	1	0	X415	.	.	0	0	-1	23	9	LOWERBD NONBASIC
18	n5	n15	23	1	0	X515	.	.	0	0	-5	24	10	LOWERBD NONBASIC
19	n6	n15	28	1	0	X615	.	.	1	28	.	25	11	KEY_ARC BASIC
20	n4	n16	25	1	0	X416	.	.	0	0	-1	26	9	LOWERBD NONBASIC
21	n5	n16	23	1	0	X516	.	.	0	0	-3	27	10	LOWERBD NONBASIC
22	n6	n16	26	1	0	X616	.	.	1	26	.	28	11	KEY_ARC BASIC
23	n4	n17	21	1	0	X417	.	.	0	0	-5	29	9	LOWERBD NONBASIC
24	n5	n17	23	1	0	X517	.	.	0	0	-3	30	10	LOWERBD NONBASIC
25	n6	n17	26	1	0	X617	.	.	1	26	.	31	11	KEY_ARC BASIC
26	n7	n18	28	1	0	X718	.	.	1	28	.	35	16	KEY_ARC BASIC
27	n8	n18	24	1	0	X818	.	.	0	0	-4	36	17	LOWERBD NONBASIC
28	n9	n18	26	1	0	X918	.	.	0	0	-2	37	18	LOWERBD NONBASIC
29	n7	n19	24	1	0	X719	.	.	1	24	.	38	16	KEY_ARC BASIC
30	n8	n19	23	1	0	X819	.	.	0	0	-1	39	17	LOWERBD NONBASIC
31	n9	n19	22	1	0	X919	.	.	0	0	-2	40	18	LOWERBD NONBASIC
32	s	n2	0	12	0	XS2	S	.	1	0	.	3	1	KEY_ARC BASIC
33	n7	n20	23	1	0	X720	.	.	1	23	.	41	16	KEY_ARC BASIC
34	n8	n20	23	1	0	X820	.	.	0	0	0	42	17	LOWERBD NONBASIC
35	n9	n20	22	1	0	X920	.	.	0	0	-1	43	18	LOWERBD NONBASIC
36	n7	n21	22	1	0	X721	.	.	1	22	.	44	16	KEY_ARC BASIC
37	n8	n21	19	1	0	X821	.	.	0	0	-3	45	17	LOWERBD NONBASIC
38	n9	n21	19	1	0	X921	.	.	0	0	-3	46	18	LOWERBD NONBASIC
39	s	n3	0	12	0	XS3	S	.	6	0	.	4	1	KEY_ARC BASIC
40	n1	n4	0	8	0	X14	.	.	5	0	.	17	2	KEY_ARC BASIC
41	n2	n5	0	8	0	X25	.	.	0	0	.	18	3	KEY_ARC BASIC
42	n3	n6	0	8	0	X36	.	.	3	0	.	19	4	KEY_ARC BASIC
43	n4	n7	0	4	0	X47	.	.	4	0	.	32	9	KEY_ARC BASIC
44	n5	n8	0	4	0	X58	.	.	0	0	0	33	10	LOWERBD NONBASIC
45	n6	n9	0	4	0	X69	.	.	0	0	0	34	11	LOWERBD NONBASIC
46	t	s	0	99999999	0	XTS	.	.	12	0	.	1	23	KEY_ARC BASIC
47	n10	t	0	1	0	X10T	.	D	1	0	27	47	5	UPPERBD NONBASIC
48	n11	t	0	1	0	X11T	.	D	1	0	23	48	6	UPPERBD NONBASIC
49	n12	t	0	1	0	X12T	.	D	1	0	28	49	7	UPPERBD NONBASIC
50	n13	t	0	1	0	X13T	.	D	1	0	25	50	8	UPPERBD NONBASIC
51	n14	t	0	1	0	X14T	.	D	1	0	21	51	12	UPPERBD NONBASIC
52	n15	t	0	1	0	X15T	.	D	1	0	28	52	13	UPPERBD NONBASIC
53	n16	t	0	1	0	X16T	.	D	1	0	26	53	14	UPPERBD NONBASIC
54	n17	t	0	1	0	X17T	.	D	1	0	26	54	15	UPPERBD NONBASIC
55	n18	t	0	1	0	X18T	.	D	1	0	28	55	19	UPPERBD NONBASIC
56	n19	t	0	1	0	X19T	.	D	1	0	24	56	20	UPPERBD NONBASIC
57	n20	t	0	1	0	X20T	.	D	1	0	23	57	21	UPPERBD NONBASIC
58	n21	t	0	1	0	X21T	.	D	1	0	22	58	22	UPPERBD NONBASIC
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Appendix H. *Network Without Side Constraints Using PROC NETFLOW*

H.1 Formulation

```
options linesize=120;
options pagesize=66;
title 'Facility Location - run 3';
title3 'Nodes for Facility Location';
   data noded;
      input _node_ $ _sd_;
      cards;
   s 0
   t 0
;
title3 'Arcs for Facility Location';
   data arcd1;
      input _from_ $ _to_ $ _cost_ _capac_ _name_ $;
      cards;
   s   n1  0  12 xs1
   s   n2  0  12 xs2
   s   n3  0  12 xs3
   n1  n10 20 1  x110
   n1  n11 22 1  x111
   n1  n12 24 1  x112
   n1  n13 21 1  x113
   n1  n4  0  8  x14
   n2  n10 23 1  x210
   n2  n11 19 1  x211
   n2  n12 28 1  x212
   n2  n13 22 1  x213
   n2  n5  0  8  x25
   n3  n10 27 1  x310
   n3  n11 23 1  x311
   n3  n12 21 1  x312
   n3  n13 25 1  x313
   n3  n6  0  8  x36
   n4  n14 21 1  x414
   n4  n15 27 1  x415
   n4  n16 25 1  x416
   n4  n17 21 1  x417
   n4  n7  0  4  x47
   n5  n14 21 1  x514
   n5  n15 23 1  x515
   n5  n16 23 1  x516
   n5  n17 23 1  x517
   n5  n8  0  4  x58
   n6  n14 19 1  x614
   n6  n15 28 1  x615
   n6  n16 26 1  x616
```

```
   n6  n17 26 1  x617
   n6  n9  0  4  x69
   n7  n18 28 1  x718
   n7  n19 24 1  x719
   n7  n20 23 1  x720
   n7  n21 22 1  x721
   n8  n18 24 1  x818
   n8  n19 23 1  x819
   n8  n20 23 1  x820
   n8  n21 19 1  x821
   n9  n18 26 1  x918
   n9  n19 22 1  x919
   n9  n20 22 1  x920
   n9  n21 19 1  x921
   n10 t   0  1  x10t
   n11 t   0  1  x11t
   n12 t   0  1  x12t
   n13 t   0  1  x13t
   n14 t   0  1  x14t
   n15 t   0  1  x15t
   n16 t   0  1  x16t
   n17 t   0  1  x17t
   n18 t   0  1  x18t
   n19 t   0  1  x19t
   n20 t   0  1  x20t
   n21 t   0  1  x21t
   t   s   0  .  xts
;
title3 'Side constraints';
data cond1;
   input xs1 xs2 xs3 x110 x111 x112 x113 x14 x210 x211 x212 x213 x25
   x310 x311 x312 x313 x36 x414 x415 x416 x417 x47 x514 x515 x516 x517 x58
   x614 x615 x616 x617 x69 x718 x719 x720 x721 x818 x819 x820 x821
   x918 x919 x920 x921 xts _type_ $ _rhs_;
   cards;

. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 1 = 12
;

proc netflow
  nodedata=noded
  arcdata=arcd1
  condata=cond1
  conout=solution
  max
  sourcenode=s
  sinknode=t
  namectrl=1;
proc print data=solution;
sum _fcost_;
```

H.2 Solution

OBS	_FROM_	_TO_	_COST_	_CAPAC_	_LO_	_NAME_	_SUPPLY_	_DEMAND_	_FLOW_	_FCOST_	_RCOST_	_ANUMB_	_TNUMB_	_STATUS_
1	s	n1	0	12	0	XS1	S	.	5	0	.	2	1	KEY_ARC BASIC
2	n1	n10	20	1	0	X110	.	.	0	0	-7	5	2	LOWERBD NONBASIC
3	n2	n10	23	1	0	X210	.	.	0	0	-4	6	3	LOWERBD NONBASIC
4	n3	n10	27	1	0	X310	.	.	1	27	.	7	4	KEY_ARC BASIC
5	n1	n11	22	1	0	X111	.	.	0	0	-1	8	2	LOWERBD NONBASIC
6	n2	n11	19	1	0	X211	.	.	0	0	-4	9	3	LOWERBD NONBASIC
7	n3	n11	23	1	0	X311	.	.	1	23	.	10	4	KEY_ARC BASIC
8	n1	n12	24	1	0	X112	.	.	0	0	-4	11	2	LOWERBD NONBASIC
9	n2	n12	28	1	0	X212	.	.	1	28	.	12	3	KEY_ARC BASIC
10	n3	n12	21	1	0	X312	.	.	0	0	-7	13	4	LOWERBD NONBASIC
11	n1	n13	21	1	0	X113	.	.	0	0	-4	14	2	LOWERBD NONBASIC
12	n2	n13	22	1	0	X213	.	.	0	0	-3	15	3	LOWERBD NONBASIC
13	n3	n13	25	1	0	X313	.	.	1	25	.	16	4	KEY_ARC BASIC
14	n4	n14	21	1	0	X414	.	.	1	21	.	20	9	KEY_ARC BASIC
15	n5	n14	21	1	0	X514	.	.	0	0	0	21	10	LOWERBD NONBASIC
16	n6	n14	19	1	0	X614	.	.	0	0	-2	22	11	LOWERBD NONBASIC
17	n4	n15	27	1	0	X415	.	.	0	0	-1	23	9	LOWERBD NONBASIC
18	n5	n15	23	1	0	X515	.	.	0	0	-5	24	10	LOWERBD NONBASIC
19	n6	n15	28	1	0	X615	.	.	1	28	.	25	11	KEY_ARC BASIC
20	n4	n16	25	1	0	X416	.	.	0	0	-1	26	9	LOWERBD NONBASIC
21	n5	n16	23	1	0	X516	.	.	0	0	-3	27	10	LOWERBD NONBASIC
22	n6	n16	26	1	0	X616	.	.	1	26	.	28	11	KEY_ARC BASIC
23	n4	n17	21	1	0	X417	.	.	0	0	-5	29	9	LOWERBD NONBASIC
24	n5	n17	23	1	0	X517	.	.	0	0	-3	30	10	LOWERBD NONBASIC
25	n6	n17	26	1	0	X617	.	.	1	26	.	31	11	KEY_ARC BASIC
26	n7	n18	28	1	0	X718	.	.	1	28	.	35	16	KEY_ARC BASIC
27	n8	n18	24	1	0	X818	.	.	0	0	-4	36	17	LOWERBD NONBASIC
28	n9	n18	26	1	0	X918	.	.	0	0	-2	37	18	LOWERBD NONBASIC
29	n7	n19	24	1	0	X719	.	.	1	24	.	38	16	KEY_ARC BASIC
30	n8	n19	23	1	0	X819	.	.	0	0	-1	39	17	LOWERBD NONBASIC
31	n9	n19	22	1	0	X919	.	.	0	0	-2	40	18	LOWERBD NONBASIC
32	s	n2	0	12	0	XS2	S	.	1	0	.	3	1	KEY_ARC BASIC
33	n7	n20	23	1	0	X720	.	.	1	23	.	41	16	KEY_ARC BASIC
34	n8	n20	23	1	0	X820	.	.	0	0	0	42	17	LOWERBD NONBASIC
35	n9	n20	22	1	0	X920	.	.	0	0	-1	43	18	LOWERBD NONBASIC
36	n7	n21	22	1	0	X721	.	.	1	22	.	44	16	KEY_ARC BASIC
37	n8	n21	19	1	0	X821	.	.	0	0	-3	45	17	LOWERBD NONBASIC
38	n9	n21	19	1	0	X921	.	.	0	0	-3	46	18	LOWERBD NONBASIC
39	s	n3	0	12	0	XS3	S	.	6	0	.	4	1	KEY_ARC BASIC
40	n1	n4	0	8	0	X14	.	.	5	0	.	17	2	KEY_ARC BASIC
41	n2	n5	0	8	0	X25	.	.	0	0	.	18	3	KEY_ARC BASIC
42	n3	n6	0	8	0	X36	.	.	3	0	.	19	4	KEY_ARC BASIC
43	n4	n7	0	4	0	X47	.	.	4	0	.	32	9	KEY_ARC BASIC
44	n5	n8	0	4	0	X58	.	.	0	0	0	33	10	LOWERBD NONBASIC
45	n6	n9	0	4	0	X69	.	.	0	0	0	34	11	LOWERBD NONBASIC
46	t	s	0	99999999	0	XTS	.	.	12	0	.	1	23	KEY_ARC BASIC
47	n10	t	0	1	0	X10T	.	D	1	0	100000026	47	5	UPPERBD NONBASIC
48	n11	t	0	1	0	X11T	.	D	1	0	100000022	48	6	UPPERBD NONBASIC
49	n12	t	0	1	0	X12T	.	D	1	0	100000027	49	7	UPPERBD NONBASIC
50	n13	t	0	1	0	X13T	.	D	1	0	100000024	50	8	UPPERBD NONBASIC
51	n14	t	0	1	0	X14T	.	D	1	0	100000020	51	12	UPPERBD NONBASIC
52	n15	t	0	1	0	X15T	.	D	1	0	100000027	52	13	UPPERBD NONBASIC
53	n16	t	0	1	0	X16T	.	D	1	0	100000025	53	14	UPPERBD NONBASIC
54	n17	t	0	1	0	X17T	.	D	1	0	100000025	54	15	UPPERBD NONBASIC
55	n18	t	0	1	0	X18T	.	D	1	0	100000027	55	19	UPPERBD NONBASIC
56	n19	t	0	1	0	X19T	.	D	1	0	100000023	56	20	UPPERBD NONBASIC
57	n20	t	0	1	0	X20T	.	D	1	0	100000022	57	21	UPPERBD NONBASIC
58	n21	t	0	1	0	X21T	.	D	1	0	100000021	58	22	UPPERBD NONBASIC
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Appendix I. *Network With Side Constraints–Formulation 4*

I.1 Formulation

```
options linesize=120;
options pagesize=66;
title 'Facility Location - run 5';
title3 'Nodes for Facility Location';
   data noded;
      input _node_ $ _sd_;
      cards;
   s 0
   t 0
;

title3 'Arcs for Facility Location';
   data arcd1;
      input _from_ $ _to_ $ _cost_ _capac_ _name_ $;
      cards;
   s   n1  0  12  xs1
   s   n2  0  12  xs2
   s   n3  0  12  xs3
   n1  n10 20 1  x110
   n1  n11 22 1  x111
   n1  n12 24 1  x112
   n1  n13 21 1  x113
   n1  n4  0  8  x14
   n2  n10 23 1  x210
   n2  n11 19 1  x211
   n2  n12 28 1  x212
   n2  n13 22 1  x213
   n2  n5  0  8  x25
   n3  n10 27 1  x310
   n3  n11 23 1  x311
   n3  n12 21 1  x312
   n3  n13 25 1  x313
   n3  n6  0  8  x36
   n4  n14 21 1  x414
   n4  n15 27 1  x415
   n4  n16 25 1  x416
   n4  n17 21 1  x417
   n4  n7  0  4  x47
   n5  n14 21 1  x514
   n5  n15 23 1  x515
   n5  n16 23 1  x516
   n5  n17 23 1  x517
   n5  n8  0  4  x58
   n6  n14 19 1  x614
   n6  n15 28 1  x615
```

```
   n6  n16 26 1  x616
   n6  n17 26 1  x617
   n6  n9  0  4  x69
   n7  n18 28 1  x718
   n7  n19 24 1  x719
   n7  n20 23 1  x720
   n7  n21 22 1  x721
   n8  n18 24 1  x818
   n8  n19 23 1  x819
   n8  n20 23 1  x820
   n8  n21 19 1  x821
   n9  n18 26 1  x918
   n9  n19 22 1  x919
   n9  n20 22 1  x920
   n9  n21 19 1  x921
   n10 t   0  1  x10t
   n11 t   0  1  x11t
   n12 t   0  1  x12t
   n13 t   0  1  x13t
   n14 t   0  1  x14t
   n15 t   0  1  x15t
   n16 t   0  1  x16t
   n17 t   0  1  x17t
   n18 t   0  1  x18t
   n19 t   0  1  x19t
   n20 t   0  1  x20t
   n21 t   0  1  x21t
   t   s   0  .  xts
;

title3 'Side constraints';
data cond1;
   input xs1 xs2 xs3 x110 x111 x112 x113 x14 x210 x211 x212 x213 x25
   x310 x311 x312 x313 x36 x414 x415 x416 x417 x47 x514 x515 x516 x517 x58
   x614 x615 x616 x617 x69 x718 x719 x720 x721 x818 x819 x820 x821
   x918 x919 x920 x921 _type_ $ _rhs_;
   cards;

-1 . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
-1 . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
-1 . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
-1 . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
-8 . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. -1 . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. -1 . . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. -1 . . . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. -1 . . . . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. -8 . . . . . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . -1 . . . . . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . -1 . . . . . . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . -1 . . . . . . . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . -1 . . . . . . . . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . -8 . . . . . . . . . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . . . . . . -1 . . . . . . . . . . 8 . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . . . . . . -1 . . . . . . . . . . . 8 . . . . . . . . . . . . . . . . . . . . . . . . . = 0
```

```
. . . . . . . -1 . . . . . . . . . . . . 8 . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . . . . . . -1 . . . . . . . . . . . . . 8 . . . . . . . . . . . . . . . . . . . . . . . = 0
. . . . . . . -1 . . . . . . . . . . . . . . 2 . . . . . . . . . . . . . . . . . . . . . . = 0
. . . . . . . . . . . . -1 . . . . . . . . . . 8 . . . . . . . . . . . . . . . . . . . . . = 0
. . . . . . . . . . . . -1 . . . . . . . . . . . 8 . . . . . . . . . . . . . . . . . . . . = 0
. . . . . . . . . . . . -1 . . . . . . . . . . . . 8 . . . . . . . . . . . . . . . . . . . = 0
. . . . . . . . . . . . -1 . . . . . . . . . . . . . 8 . . . . . . . . . . . . . . . . . . = 0
. . . . . . . . . . . . -1 . . . . . . . . . . . . . . 2 . . . . . . . . . . . . . . . . . = 0
. . . . . . . . . . . . . . . . . -1 . . . . . . . . . . 8 . . . . . . . . . . . . . . . . = 0
. . . . . . . . . . . . . . . . . -1 . . . . . . . . . . . 8 . . . . . . . . . . . . . . . = 0
. . . . . . . . . . . . . . . . . -1 . . . . . . . . . . . . 8 . . . . . . . . . . . . . . = 0
. . . . . . . . . . . . . . . . . -1 . . . . . . . . . . . . . 8 . . . . . . . . . . . . . = 0
. . . . . . . . . . . . . . . . . -1 . . . . . . . . . . . . . . 2 . . . . . . . . . . . . = 0
. . . . . . . . . . . . . . . . . . . . . . -1 . . . . . . . . . . 4 . . . . . . . . . . . = 0
. . . . . . . . . . . . . . . . . . . . . . -1 . . . . . . . . . . . 4 . . . . . . . . . . = 0
. . . . . . . . . . . . . . . . . . . . . . -1 . . . . . . . . . . . . 4 . . . . . . . . . = 0
. . . . . . . . . . . . . . . . . . . . . . -1 . . . . . . . . . . . . . 4 . . . . . . . . = 0
. . . . . . . . . . . . . . . . . . . . . . . . . . . -1 . . . . . . . . . 4 . . . . . . . = 0
. . . . . . . . . . . . . . . . . . . . . . . . . . . -1 . . . . . . . . . . 4 . . . . . . = 0
. . . . . . . . . . . . . . . . . . . . . . . . . . . -1 . . . . . . . . . . . 4 . . . . . = 0
. . . . . . . . . . . . . . . . . . . . . . . . . . . -1 . . . . . . . . . . . . 4 . . . . = 0
. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . -1 . . . . . . . . 4 . . . = 0
. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . -1 . . . . . . . . . 4 . . = 0
. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . -1 . . . . . . . . . . 4 . = 0
. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . -1 . . . . . . . . . . . 4 = 0
;

proc netflow
  nodedata=noded
  arcdata=arcd1
  condata=cond1
  conout=solution
  max
  sourcenode=s
  sinknode=t
  namectrl=1;

proc print data=solution;
sum _fcost_;
```

I.2 Solution

OBS	_FROM_	_TO_	_COST_	_CAPAC_	_LO_	_NAME_	_SUPPLY_	_DEMAND_	_FLOW_	_FCOST_	_RCOST_	_ANUMB_	_TNUMB_	_STATUS_
1	s	n1	0	12	0	XS1	S	.	0	0	.	2	1	KEY_ARC BASIC
2	n1	n10	20	1	0	X110	.	.	0	0	-6.0000	5	2	LOWERBD NONBASIC
3	n2	n10	23	1	0	X210	.	.	0	0	.	6	3	NONKEY ARC BASIC
4	n3	n10	27	1	0	X310	.	.	1	27	.	7	4	KEY_ARC BASIC
5	n1	n11	22	1	0	X111	.	.	0	0	.	8	2	NONKEY ARC BASIC
6	n2	n11	19	1	0	X211	.	.	0	0	.	9	3	NONKEY ARC BASIC
7	n3	n11	23	1	0	X311	.	.	1	23	.	10	4	KEY_ARC BASIC
8	n1	n12	24	1	0	X112	.	.	0	0	.	11	2	NONKEY ARC BASIC
9	n2	n12	28	1	0	X212	.	.	0	0	.	12	3	KEY_ARC BASIC
10	n3	n12	21	1	0	X312	.	.	1	21	.	13	4	NONKEY ARC BASIC
11	n1	n13	21	1	0	X113	.	.	0	0	.	14	2	NONKEY ARC BASIC
12	n2	n13	22	1	0	X213	.	.	0	0	.	15	3	NONKEY ARC BASIC
13	n3	n13	25	1	0	X313	.	.	1	25	.	16	4	KEY_ARC BASIC
14	n4	n14	21	1	0	X414	.	.	0	0	.	20	9	KEY_ARC BASIC
15	n5	n14	21	1	0	X514	.	.	0	0	.	21	10	NONKEY ARC BASIC
16	n6	n14	19	1	0	X614	.	.	1	19	.	22	11	NONKEY ARC BASIC
17	n4	n15	27	1	0	X415	.	.	0	0	.	23	9	NONKEY ARC BASIC
18	n5	n15	23	1	0	X515	.	.	0	0	.	24	10	NONKEY ARC BASIC
19	n6	n15	28	1	0	X615	.	.	1	28	.	25	11	KEY_ARC BASIC
20	n4	n16	25	1	0	X416	.	.	0	0	.	26	9	NONKEY ARC BASIC
21	n5	n16	23	1	0	X516	.	.	0	0	.	27	10	NONKEY ARC BASIC
22	n6	n16	26	1	0	X616	.	.	1	26	.	28	11	KEY_ARC BASIC
23	n4	n17	21	1	0	X417	.	.	0	0	.	29	9	NONKEY ARC BASIC
24	n5	n17	23	1	0	X517	.	.	0	0	.	30	10	NONKEY ARC BASIC
25	n6	n17	26	1	0	X617	.	.	1	26	.	31	11	KEY_ARC BASIC
26	n7	n18	28	1	0	X718	.	.	0	0	.	35	16	KEY_ARC BASIC
27	n8	n18	24	1	0	X818	.	.	0	0	-3.0000	36	17	LOWERBD NONBASIC
28	n9	n18	26	1	0	X918	.	.	1	26	.	37	18	NONKEY ARC BASIC
29	n7	n19	24	1	0	X719	.	.	0	0	.	38	16	KEY_ARC BASIC
30	n8	n19	23	1	0	X819	.	.	0	0	.	39	17	NONKEY ARC BASIC
31	n9	n19	22	1	0	X919	.	.	1	22	.	40	18	NONKEY ARC BASIC
32	s	n2	0	12	0	XS2	S	.	0	0	.	3	1	KEY_ARC BASIC
33	n7	n20	23	1	0	X720	.	.	0	0	.	41	16	KEY_ARC BASIC
34	n8	n20	23	1	0	X820	.	.	0	0	0.0000	42	17	LOWERBD NONBASIC
35	n9	n20	22	1	0	X920	.	.	1	22	.	43	18	NONKEY ARC BASIC
36	n7	n21	22	1	0	X721	.	.	0	0	.	44	16	KEY_ARC BASIC
37	n8	n21	19	1	0	X821	.	.	0	0	-1.0000	45	17	LOWERBD NONBASIC
38	n9	n21	19	1	0	X921	.	.	1	19	.	46	18	NONKEY ARC BASIC
39	s	n3	0	12	0	XS3	S	.	12	0	.	4	1	KEY_ARC BASIC
40	n1	n4	0	8	0	X14	.	.	0	0	.	17	2	KEY_ARC BASIC
41	n2	n5	0	8	0	X25	.	.	0	0	.	18	3	KEY_ARC BASIC
42	n3	n6	0	8	0	X36	.	.	8	0	.	19	4	KEY_ARC BASIC
43	n4	n7	0	4	0	X47	.	.	0	0	.	32	9	KEY_ARC BASIC
44	n5	n8	0	4	0	X58	.	.	0	0	-2.2500	33	10	LOWERBD NONBASIC
45	n6	n9	0	4	0	X69	.	.	4	0	.	34	11	KEY_ARC BASIC
46	t	s	0	99999999	0	XTS	.	.	12	0	.	1	23	KEY_ARC BASIC
47	n10	t	0	1	0	X10T	.	D	1	0	.	47	5	NONKEY ARC BASIC
48	n11	t	0	1	0	X11T	.	D	1	0	.	48	6	NONKEY ARC BASIC
49	n12	t	0	1	0	X12T	.	D	1	0	.	49	7	NONKEY ARC BASIC
50	n13	t	0	1	0	X13T	.	D	1	0	.	50	8	NONKEY ARC BASIC
51	n14	t	0	1	0	X14T	.	D	1	0	.	51	12	NONKEY ARC BASIC
52	n15	t	0	1	0	X15T	.	D	1	0	.	52	13	NONKEY ARC BASIC
53	n16	t	0	1	0	X16T	.	D	1	0	.	53	14	NONKEY ARC BASIC
54	n17	t	0	1	0	X17T	.	D	1	0	.	54	15	NONKEY ARC BASIC
55	n18	t	0	1	0	X18T	.	D	1	0	74.7500	55	19	UPPERBD NONBASIC
56	n19	t	0	1	0	X19T	.	D	1	0	70.7500	56	20	UPPERBD NONBASIC
57	n20	t	0	1	0	X20T	.	D	1	0	70.7500	57	21	UPPERBD NONBASIC
58	n21	t	0	1	0	X21T	.	D	1	0	67.7500	58	22	UPPERBD NONBASIC
										=======				
										284				

Appendix J. *Network With Side Constraints–Formulation 4 Reduced*

J.1 Formulation

```
options linesize=120;
options pagesize=66;
title 'Facility Location - run 6';
title3 'Nodes for Facility Location';
   data noded;
      input _node_ $ _sd_;
      cards;
   s 0
   t 0
;

title3 'Arcs for Facility Location';
   data arcd1;
      input _from_ $ _to_ $ _cost_ _capac_ _name_ $;
      cards;
   s   n1  0  12  xs1
   s   n2  0  12  xs2
   s   n3  0  12  xs3
   n1  n10 20 1  x110
   n1  n11 22 1  x111
   n1  n12 24 1  x112
   n1  n13 21 1  x113
   n1  n4  0  8  x14
   n2  n10 23 1  x210
   n2  n11 19 1  x211
   n2  n12 28 1  x212
   n2  n13 22 1  x213
   n2  n5  0  8  x25
   n3  n10 27 1  x310
   n3  n11 23 1  x311
   n3  n12 21 1  x312
   n3  n13 25 1  x313
   n3  n6  0  8  x36
   n4  n14 21 1  x414
   n4  n15 27 1  x415
   n4  n16 25 1  x416
   n4  n17 21 1  x417
   n4  n7  0  4  x47
   n5  n14 21 1  x514
   n5  n15 23 1  x515
   n5  n16 23 1  x516
   n5  n17 23 1  x517
   n5  n8  0  4  x58
   n6  n14 19 1  x614
   n6  n15 28 1  x615
```

```
   n6  n16 26 1  x616
   n6  n17 26 1  x617
   n6  n9  0  4  x69
   n7  n18 28 1  x718
   n7  n19 24 1  x719
   n7  n20 23 1  x720
   n7  n21 22 1  x721
   n8  n18 24 1  x818
   n8  n19 23 1  x819
   n8  n20 23 1  x820
   n8  n21 19 1  x821
   n9  n18 26 1  x918
   n9  n19 22 1  x919
   n9  n20 22 1  x920
   n9  n21 19 1  x921
   n10 t   0  1  x10t
   n11 t   0  1  x11t
   n12 t   0  1  x12t
   n13 t   0  1  x13t
   n14 t   0  1  x14t
   n15 t   0  1  x15t
   n16 t   0  1  x16t
   n17 t   0  1  x17t
   n18 t   0  1  x18t
   n19 t   0  1  x19t
   n20 t   0  1  x20t
   n21 t   0  1  x21t
   t   s   0  .  xts
;

title3 'Side constraints';
data cond1;
   input xs1 xs2 xs3 x110 x111 x112 x113 x14 x210 x211 x212 x213 x25
   x310 x311 x312 x313 x36 x414 x415 x416 x417 x47 x514 x515 x516 x517 x58
   x614 x615 x616 x617 x69 x718 x719 x720 x721 x818 x819 x820 x821
   x918 x919 x920 x921 _type_ $ _rhs_;
   cards;

-1 . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
-1 . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
-1 . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
-1 . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
-8 . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. -1 . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. -1 . . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. -1 . . . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. -1 . . . . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. -8 . . . . . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . -1 . . . . . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . -1 . . . . . . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . -1 . . . . . . . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . -1 . . . . . . . . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . -8 . . . . . . . . . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . . . . . . -1 . . . . . . . . . . 8 . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . . . . . . -1 . . . . . . . . . . . 8 . . . . . . . . . . . . . . . . . . . . . . . . . = 0
```

```
. . . . . . . . . -1 . . . . . . . . . . . . . . 8 . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . . . . . . . . -1 . . . . . . . . . . . . . . . 8 . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . . . . . . . . -1 . . . . . . . . . . . . . . . . 2 . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . . . . . . . . . . . . . . -1 . . . . . . . . . . . 8 . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . . . . . . . . . . . . . . -1 . . . . . . . . . . . . 8 . . . . . . . . . . . . . . . . . . . . . . . = 0
. . . . . . . . . . . . . . . -1 . . . . . . . . . . . . . 8 . . . . . . . . . . . . . . . . . . . . . . = 0
. . . . . . . . . . . . . . . -1 . . . . . . . . . . . . . . 8 . . . . . . . . . . . . . . . . . . . . . = 0
. . . . . . . . . . . . . . . -1 . . . . . . . . . . . . . . . 2 . . . . . . . . . . . . . . . . . . . . = 0
. . . . . . . . . . . . . . . . . . . . -1 . . . . . . . . . . . . 8 . . . . . . . . . . . . . . . . . . = 0
. . . . . . . . . . . . . . . . . . . . -1 . . . . . . . . . . . . . 8 . . . . . . . . . . . . . . . . . = 0
. . . . . . . . . . . . . . . . . . . . -1 . . . . . . . . . . . . . . 8 . . . . . . . . . . . . . . . . = 0
. . . . . . . . . . . . . . . . . . . . -1 . . . . . . . . . . . . . . . 8 . . . . . . . . . . . . . . . = 0
. . . . . . . . . . . . . . . . . . . . -1 . . . . . . . . . . . . . . . . 2 . . . . . . . . . . . . . . = 0
;

proc netflow
  nodedata=noded
  arcdata=arcd1
  condata=cond1
  conout=solution
  max
  sourcenode=s
  sinknode=t
  namectrl=1;

proc print data=solution;
sum _fcost_;
```

J.2 Solution

OBS	_FROM_	_TO_	_COST_	_CAPAC_	_LO_	_NAME_	_SUPPLY_	_DEMAND_	_FLOW_	_FCOST_	_RCOST_	_ANUMB_	_TNUMB_	_STATUS_
1	s	n1	0	12	0	XS1	S	.	0	0	.	2	1	KEY_ARC BASIC
2	n1	n10	20	1	0	X110	.	.	0	0	.	5	2	KEY_ARC BASIC
3	n2	n10	23	1	0	X210	.	.	0	0	.	6	3	NONKEY ARC BASIC
4	n3	n10	27	1	0	X310	.	.	1	27	.	7	4	NONKEY ARC BASIC
5	n1	n11	22	1	0	X111	.	.	0	0	.	8	2	NONKEY ARC BASIC
6	n2	n11	19	1	0	X211	.	.	0	0	.	9	3	NONKEY ARC BASIC
7	n3	n11	23	1	0	X311	.	.	1	23	.	10	4	KEY_ARC BASIC
8	n1	n12	24	1	0	X112	.	.	0	0	-2.0000	11	2	LOWERBD NONBASIC
9	n2	n12	28	1	0	X212	.	.	0	0	.	12	3	KEY_ARC BASIC
10	n3	n12	21	1	0	X312	.	.	1	21	.	13	4	NONKEY ARC BASIC
11	n1	n13	21	1	0	X113	.	.	0	0	.	14	2	NONKEY ARC BASIC
12	n2	n13	22	1	0	X213	.	.	0	0	.	15	3	NONKEY ARC BASIC
13	n3	n13	25	1	0	X313	.	.	1	25	.	16	4	KEY_ARC BASIC
14	n4	n14	21	1	0	X414	.	.	0	0	.	20	9	KEY_ARC BASIC
15	n5	n14	21	1	0	X514	.	.	0	0	-1.0000	21	10	LOWERBD NONBASIC
16	n6	n14	19	1	0	X614	.	.	1	19	.	22	11	NONKEY ARC BASIC
17	n4	n15	27	1	0	X415	.	.	0	0	.	23	9	NONKEY ARC BASIC
18	n5	n15	23	1	0	X515	.	.	0	0	.	24	10	NONKEY ARC BASIC
19	n6	n15	28	1	0	X615	.	.	1	28	.	25	11	KEY_ARC BASIC
20	n4	n16	25	1	0	X416	.	.	0	0	.	26	9	NONKEY ARC BASIC
21	n5	n16	23	1	0	X516	.	.	0	0	.	27	10	NONKEY ARC BASIC
22	n6	n16	26	1	0	X616	.	.	1	26	.	28	11	KEY_ARC BASIC
23	n4	n17	21	1	0	X417	.	.	0	0	.	29	9	NONKEY ARC BASIC
24	n5	n17	23	1	0	X517	.	.	0	0	.	30	10	NONKEY ARC BASIC
25	n6	n17	26	1	0	X617	.	.	1	26	.	31	11	KEY_ARC BASIC
26	n7	n18	28	1	0	X718	.	.	0	0	.	35	16	KEY_ARC BASIC
27	n8	n18	24	1	0	X818	.	.	0	0	-4.0000	36	17	LOWERBD NONBASIC
28	n9	n18	26	1	0	X918	.	.	1	26	1.0000	37	18	UPPERBD NONBASIC
29	n7	n19	24	1	0	X719	.	.	0	0	.	38	16	KEY_ARC BASIC
30	n8	n19	23	1	0	X819	.	.	0	0	-1.0000	39	17	LOWERBD NONBASIC
31	n9	n19	22	1	0	X919	.	.	1	22	1.0000	40	18	UPPERBD NONBASIC
32	s	n2	0	12	0	XS2	S	.	0	0	.	3	1	KEY_ARC BASIC
33	n7	n20	23	1	0	X720	.	.	0	0	.	41	16	KEY_ARC BASIC
34	n8	n20	23	1	0	X820	.	.	0	0	0.0000	42	17	LOWERBD NONBASIC
35	n9	n20	22	1	0	X920	.	.	1	22	2.0000	43	18	UPPERBD NONBASIC
36	n7	n21	22	1	0	X721	.	.	0	0	.	44	16	KEY_ARC BASIC
37	n8	n21	19	1	0	X821	.	.	0	0	-3.0000	45	17	LOWERBD NONBASIC
38	n9	n21	19	1	0	X921	.	.	1	19	.	46	18	NONKEY ARC BASIC
39	s	n3	0	12	0	XS3	S	.	12	0	.	4	1	KEY_ARC BASIC
40	n1	n4	0	8	0	X14	.	.	0	0	.	17	2	KEY_ARC BASIC
41	n2	n5	0	8	0	X25	.	.	0	0	.	18	3	KEY_ARC BASIC
42	n3	n6	0	8	0	X36	.	.	8	0	.	19	4	KEY_ARC BASIC
43	n4	n7	0	4	0	X47	.	.	0	0	.	32	9	KEY_ARC BASIC
44	n5	n8	0	4	0	X58	.	.	0	0	.	33	10	NONKEY ARC BASIC
45	n6	n9	0	4	0	X69	.	.	4	0	.	34	11	KEY_ARC BASIC
46	t	s	0	99999999	0	XTS	.	.	12	0	.	1	23	KEY_ARC BASIC
47	n10	t	0	1	0	X10T	.	D	1	0	.	47	5	NONKEY ARC BASIC
48	n11	t	0	1	0	X11T	.	D	1	0	.	48	6	NONKEY ARC BASIC
49	n12	t	0	1	0	X12T	.	D	1	0	.	49	7	NONKEY ARC BASIC
50	n13	t	0	1	0	X13T	.	D	1	0	.	50	8	NONKEY ARC BASIC
51	n14	t	0	1	0	X14T	.	D	1	0	.	51	12	NONKEY ARC BASIC
52	n15	t	0	1	0	X15T	.	D	1	0	.	52	13	NONKEY ARC BASIC
53	n16	t	0	1	0	X16T	.	D	1	0	.	53	14	NONKEY ARC BASIC
54	n17	t	0	1	0	X17T	.	D	1	0	.	54	15	NONKEY ARC BASIC
55	n18	t	0	1	0	X18T	.	D	1	0	73.7500	55	19	UPPERBD NONBASIC
56	n19	t	0	1	0	X19T	.	D	1	0	69.7500	56	20	UPPERBD NONBASIC
57	n20	t	0	1	0	X20T	.	D	1	0	68.7500	57	21	UPPERBD NONBASIC
58	n21	t	0	1	0	X21T	.	D	1	0	67.7500	58	22	UPPERBD NONBASIC
										=======				
										284				

Appendix K. *Network With Side Constraints–Formulation 4 Reduced Further*

K.1 Formulation

```
options linesize=120;
options pagesize=66;
title 'Facility Location - run 7';
title3 'Nodes for Facility Location';
   data noded;
      input _node_ $ _sd_;
      cards;
   s 0
   t 0
;

title3 'Arcs for Facility Location';
   data arcd1;
      input _from_ $ _to_ $ _cost_ _capac_ _name_ $;
      cards;
   s   n1  0  12  xs1
   s   n2  0  12  xs2
   s   n3  0  12  xs3
   n1  n10 20 1  x110
   n1  n11 22 1  x111
   n1  n12 24 1  x112
   n1  n13 21 1  x113
   n1  n4  0  8  x14
   n2  n10 23 1  x210
   n2  n11 19 1  x211
   n2  n12 28 1  x212
   n2  n13 22 1  x213
   n2  n5  0  8  x25
   n3  n10 27 1  x310
   n3  n11 23 1  x311
   n3  n12 21 1  x312
   n3  n13 25 1  x313
   n3  n6  0  8  x36
   n4  n14 21 1  x414
   n4  n15 27 1  x415
   n4  n16 25 1  x416
   n4  n17 21 1  x417
   n4  n7  0  4  x47
   n5  n14 21 1  x514
   n5  n15 23 1  x515
   n5  n16 23 1  x516
   n5  n17 23 1  x517
   n5  n8  0  4  x58
   n6  n14 19 1  x614
   n6  n15 28 1  x615
```

```
   n6  n16 26 1  x616
   n6  n17 26 1  x617
   n6  n9  0  4  x69
   n7  n18 28 1  x718
   n7  n19 24 1  x719
   n7  n20 23 1  x720
   n7  n21 22 1  x721
   n8  n18 24 1  x818
   n8  n19 23 1  x819
   n8  n20 23 1  x820
   n8  n21 19 1  x821
   n9  n18 26 1  x918
   n9  n19 22 1  x919
   n9  n20 22 1  x920
   n9  n21 19 1  x921
   n10 t   0  1  x10t
   n11 t   0  1  x11t
   n12 t   0  1  x12t
   n13 t   0  1  x13t
   n14 t   0  1  x14t
   n15 t   0  1  x15t
   n16 t   0  1  x16t
   n17 t   0  1  x17t
   n18 t   0  1  x18t
   n19 t   0  1  x19t
   n20 t   0  1  x20t
   n21 t   0  1  x21t
   t   s   0  .  xts
;

title3 'Side constraints';
data cond1;
   input xs1 xs2 xs3 x110 x111 x112 x113 x14 x210 x211 x212 x213 x25
   x310 x311 x312 x313 x36 x414 x415 x416 x417 x47 x514 x515 x516 x517 x58
   x614 x615 x616 x617 x69 x718 x719 x720 x721 x818 x819 x820 x821
   x918 x919 x920 x921 _type_ $ _rhs_;
   cards;
-1 . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
-1 . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
-1 . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
-1 . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
-8 . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. -1 . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. -1 . . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. -1 . . . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. -1 . . . . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. -8 . . . . . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . -1 . . . . . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . -1 . . . . . . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . -1 . . . . . . . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . -1 . . . . . . . . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . -8 . . . . . . . . . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
;
```

```
proc netflow
  nodedata=noded
  arcdata=arcd1
  condata=cond1
  conout=solution
  max
  sourcenode=s
  sinknode=t
  namectrl=1;

proc print data=solution;
sum _fcost_;
```

K.2 Solution

OBS	_FROM_	_TO_	_COST_	_CAPAC_	_LO_	_NAME_	_SUPPLY_	_DEMAND_	_FLOW_	_FCOST_	_RCOST_	_ANUMB_	_TNUMB_	_STATUS_
1	s	n1	0	12	0	XS1	S	.	4.500	0.000	.	2	1	KEY_ARC BASIC
2	n1	n10	20	1	0	X110	.	.	0.375	7.500	.	5	2	NONKEY ARC BASIC
3	n2	n10	23	1	0	X210	.	.	0.250	5.750	.	6	3	NONKEY ARC BASIC
4	n3	n10	27	1	0	X310	.	.	0.375	10.125	.	7	4	KEY_ARC BASIC
5	n1	n11	22	1	0	X111	.	.	0.375	8.250	.	8	2	NONKEY ARC BASIC
6	n2	n11	19	1	0	X211	.	.	0.250	4.750	.	9	3	NONKEY ARC BASIC
7	n3	n11	23	1	0	X311	.	.	0.375	8.625	.	10	4	KEY_ARC BASIC
8	n1	n12	24	1	0	X112	.	.	0.375	9.000	.	11	2	NONKEY ARC BASIC
9	n2	n12	28	1	0	X212	.	.	0.250	7.000	.	12	3	KEY_ARC BASIC
10	n3	n12	21	1	0	X312	.	.	0.375	7.875	.	13	4	NONKEY ARC BASIC
11	n1	n13	21	1	0	X113	.	.	0.375	7.875	.	14	2	NONKEY ARC BASIC
12	n2	n13	22	1	0	X213	.	.	0.250	5.500	.	15	3	NONKEY ARC BASIC
13	n3	n13	25	1	0	X313	.	.	0.375	9.375	.	16	4	KEY_ARC BASIC
14	n4	n14	21	1	0	X414	.	.	0.000	0.000	.	20	9	KEY_ARC BASIC
15	n5	n14	21	1	0	X514	.	.	1.000	21.000	0.625	21	10	UPPERBD NONBASIC
16	n6	n14	19	1	0	X614	.	.	0.000	0.000	-0.875	22	11	LOWERBD NONBASIC
17	n4	n15	27	1	0	X415	.	.	0.000	0.000	-2.125	23	9	LOWERBD NONBASIC
18	n5	n15	23	1	0	X515	.	.	0.000	0.000	-5.500	24	10	LOWERBD NONBASIC
19	n6	n15	28	1	0	X615	.	.	1.000	28.000	.	25	11	KEY_ARC BASIC
20	n4	n16	25	1	0	X416	.	.	0.000	0.000	-2.125	26	9	LOWERBD NONBASIC
21	n5	n16	23	1	0	X516	.	.	0.000	0.000	-3.500	27	10	LOWERBD NONBASIC
22	n6	n16	26	1	0	X616	.	.	1.000	26.000	.	28	11	KEY_ARC BASIC
23	n4	n17	21	1	0	X417	.	.	0.000	0.000	-6.125	29	9	LOWERBD NONBASIC
24	n5	n17	23	1	0	X517	.	.	0.000	0.000	-3.500	30	10	LOWERBD NONBASIC
25	n6	n17	26	1	0	X617	.	.	1.000	26.000	.	31	11	KEY_ARC BASIC
26	n7	n18	28	1	0	X718	.	.	1.000	28.000	.	35	16	KEY_ARC BASIC
27	n8	n18	24	1	0	X818	.	.	0.000	0.000	-3.375	36	17	LOWERBD NONBASIC
28	n9	n18	26	1	0	X918	.	.	0.000	0.000	-0.875	37	18	LOWERBD NONBASIC
29	n7	n19	24	1	0	X719	.	.	1.000	24.000	.	38	16	KEY_ARC BASIC
30	n8	n19	23	1	0	X819	.	.	0.000	0.000	-0.375	39	17	LOWERBD NONBASIC
31	n9	n19	22	1	0	X919	.	.	0.000	0.000	-0.875	40	18	LOWERBD NONBASIC
32	s	n2	0	12	0	XS2	S	.	3.000	0.000	.	3	1	KEY_ARC BASIC
33	n7	n20	23	1	0	X720	.	.	0.000	0.000	-0.625	41	16	LOWERBD NONBASIC
34	n8	n20	23	1	0	X820	.	.	1.000	23.000	.	42	17	KEY_ARC BASIC
35	n9	n20	22	1	0	X920	.	.	0.000	0.000	-0.500	43	18	LOWERBD NONBASIC
36	n7	n21	22	1	0	X721	.	.	1.000	22.000	.	44	16	KEY_ARC BASIC
37	n8	n21	19	1	0	X821	.	.	0.000	0.000	-2.375	45	17	LOWERBD NONBASIC
38	n9	n21	19	1	0	X921	.	.	0.000	0.000	-1.875	46	18	LOWERBD NONBASIC
39	s	n3	0	12	0	XS3	S	.	4.500	0.000	.	4	1	KEY_ARC BASIC
40	n1	n4	0	8	0	X14	.	.	3.000	0.000	.	17	2	KEY_ARC BASIC
41	n2	n5	0	8	0	X25	.	.	2.000	0.000	.	18	3	KEY_ARC BASIC
42	n3	n6	0	8	0	X36	.	.	3.000	0.000	.	19	4	KEY_ARC BASIC
43	n4	n7	0	4	0	X47	.	.	3.000	0.000	.	32	9	KEY_ARC BASIC
44	n5	n8	0	4	0	X58	.	.	1.000	0.000	.	33	10	KEY_ARC BASIC
45	n6	n9	0	4	0	X69	.	.	0.000	0.000	.	34	11	KEY_ARC BASIC
46	t	s	0	99999999	0	XTS	.	.	12.000	0.000	.	1	23	KEY_ARC BASIC
47	n10	t	0	1	0	X10T	.	D	1.000	0.000	.	47	5	NONKEY ARC BASIC
48	n11	t	0	1	0	X11T	.	D	1.000	0.000	.	48	6	NONKEY ARC BASIC
49	n12	t	0	1	0	X12T	.	D	1.000	0.000	255.000	49	7	UPPERBD NONBASIC
50	n13	t	0	1	0	X13T	.	D	1.000	0.000	.	50	8	NONKEY ARC BASIC
51	n14	t	0	1	0	X14T	.	D	1.000	0.000	.	51	12	NONKEY ARC BASIC
52	n15	t	0	1	0	X15T	.	D	1.000	0.000	8.125	52	13	UPPERBD NONBASIC
53	n16	t	0	1	0	X16T	.	D	1.000	0.000	6.125	53	14	UPPERBD NONBASIC
54	n17	t	0	1	0	X17T	.	D	1.000	0.000	6.125	54	15	UPPERBD NONBASIC
55	n18	t	0	1	0	X18T	.	D	1.000	0.000	7.000	55	19	UPPERBD NONBASIC
56	n19	t	0	1	0	X19T	.	D	1.000	0.000	3.000	56	20	UPPERBD NONBASIC
57	n20	t	0	1	0	X20T	.	D	1.000	0.000	2.625	57	21	UPPERBD NONBASIC
58	n21	t	0	1	0	X21T	.	D	1.000	0.000	1.000	58	22	UPPERBD NONBASIC
										=======				
										289.625				

Appendix L. *NWSC Multi-Commodity Flow Formulation 1*

L.1 Formulation

```
options linesize=120;
options pagesize=66;
title 'Facility Location - run 8';
title3 'Nodes for Facility Location';
   data noded;
      input _node_ $ _sd_;
      cards;
   n1 0
   n2 0
   n3 0
   n4 0
   n5 0
   n6 0
   n7 0
   n8 0
   n9 0
   t  0
;

title3 'Arcs for Facility Location';
   data arcd1;
      input _from_ $ _to_ $ _cost_ _capac_ _name_ $;
      cards;
   n1  n10 20 1  x110
   n1  n11 22 1  x111
   n1  n12 24 1  x112
   n1  n13 21 1  x113
   n2  n10 23 1  x210
   n2  n11 19 1  x211
   n2  n12 28 1  x212
   n2  n13 22 1  x213
   n3  n10 27 1  x310
   n3  n11 23 1  x311
   n3  n12 21 1  x312
   n3  n13 25 1  x313
   n4  n14 21 1  x414
   n4  n15 27 1  x415
   n4  n16 25 1  x416
   n4  n17 21 1  x417
   n5  n14 21 1  x514
   n5  n15 23 1  x515
   n5  n16 23 1  x516
   n5  n17 23 1  x517
   n6  n14 19 1  x614
   n6  n15 28 1  x615
```

```
   n6  n16 26 1  x616
   n6  n17 26 1  x617
   n7  n18 28 1  x718
   n7  n19 24 1  x719
   n7  n20 23 1  x720
   n7  n21 22 1  x721
   n8  n18 24 1  x818
   n8  n19 23 1  x819
   n8  n20 23 1  x820
   n8  n21 19 1  x821
   n9  n18 26 1  x918
   n9  n19 22 1  x919
   n9  n20 22 1  x920
   n9  n21 19 1  x921
   n10 t   0  1  x10t
   n11 t   0  1  x11t
   n12 t   0  1  x12t
   n13 t   0  1  x13t
   n14 t   0  1  x14t
   n15 t   0  1  x15t
   n16 t   0  1  x16t
   n17 t   0  1  x17t
   n18 t   0  1  x18t
   n19 t   0  1  x19t
   n20 t   0  1  x20t
   n21 t   0  1  x21t
   t   n1  0  .  xt1
   t   n2  0  .  xt2
   t   n3  0  .  xt3
   t   n4  0  .  xt4
   t   n5  0  .  xt5
   t   n6  0  .  xt6
   t   n7  0  .  xt7
   t   n8  0  .  xt8
   t   n9  0  .  xt9
;

title3 'Side constraints';
data cond1;
   input
   x110 x111 x112 x113 x210 x211 x212 x213 x310 x311 x312 x313 x414 x415 x416
   x417 x514 x515 x516 x517 x614 x615 x616 x617 x718 x719 x720 x721 x818 x819
   x820 x821 x918 x919 x920 x921 xt1 xt2 xt3 xt4 xt5 xt6 xt7 xt8 xt9
   _type_ $ _rhs_;
   cards;

. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . . . . -1 . . 1 . . . . . eq 0
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . . . . -1 . . . . . 1 . . eq 0
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . . . . . -1 . . 1 . . . . eq 0
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . . . . . -1 . . . . . 1 . eq 0
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . . . . . . -1 . . 1 . . . eq 0
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . . . . . . -1 . . . . . 1 eq 0
;
```

```
proc netflow
  nodedata=noded
  arcdata=arcd1
  condata=cond1
  conout=solution
  max
  sourcenode=s
  sinknode=t
  namectrl=1;

proc print data=solution;
sum _fcost_;
```

L.2 Solution

OBS	_FROM_	_TO_	_COST_	_CAPAC_	_LO_	_NAME_	_SUPPLY_	_DEMAND_	_FLOW_	_FCOST_	_RCOST_	_ANUMB_	_TNUMB_	_STATUS_
1	t	n1	0	99999999	0	XT1	.	.	1	0	.	1	22	KEY_ARC BASIC
2	n1	n10	20	1	0	X110	.	.	0	0	-6	2	1	LOWERBD NONBASIC
3	n2	n10	23	1	0	X210	.	.	0	0	-6	3	6	LOWERBD NONBASIC
4	n3	n10	27	1	0	X310	.	.	1	27	.	4	7	KEY_ARC BASIC
5	n1	n11	22	1	0	X111	.	.	1	22	0	5	1	UPPERBD NONBASIC
6	n2	n11	19	1	0	X211	.	.	0	0	-6	6	6	LOWERBD NONBASIC
7	n3	n11	23	1	0	X311	.	.	0	0	.	7	7	KEY_ARC BASIC
8	n1	n12	24	1	0	X112	.	.	0	0	-1	8	1	LOWERBD NONBASIC
9	n2	n12	28	1	0	X212	.	.	1	28	.	9	6	KEY_ARC BASIC
10	n3	n12	21	1	0	X312	.	.	0	0	-5	10	7	LOWERBD NONBASIC
11	n1	n13	21	1	0	X113	.	.	0	0	-3	11	1	LOWERBD NONBASIC
12	n2	n13	22	1	0	X213	.	.	0	0	-5	12	6	LOWERBD NONBASIC
13	n3	n13	25	1	0	X313	.	.	1	25	.	13	7	KEY_ARC BASIC
14	n4	n14	21	1	0	X414	.	.	0	0	.	17	8	KEY_ARC BASIC
15	n5	n14	21	1	0	X514	.	.	1	21	2	18	13	UPPERBD NONBASIC
16	n6	n14	19	1	0	X614	.	.	0	0	-3	19	14	LOWERBD NONBASIC
17	n4	n15	27	1	0	X415	.	.	1	27	0	20	8	UPPERBD NONBASIC
18	n5	n15	23	1	0	X515	.	.	0	0	-2	21	13	LOWERBD NONBASIC
19	n6	n15	28	1	0	X615	.	.	0	0	.	22	14	KEY_ARC BASIC
20	n4	n16	25	1	0	X416	.	.	0	0	.	23	8	NONKEY ARC BASIC
21	n5	n16	23	1	0	X516	.	.	0	0	.	24	13	NONKEY ARC BASIC
22	n6	n16	26	1	0	X616	.	.	1	26	.	25	14	KEY_ARC BASIC
23	n4	n17	21	1	0	X417	.	.	0	0	-4	26	8	LOWERBD NONBASIC
24	n5	n17	23	1	0	X517	.	.	0	0	0	27	13	LOWERBD NONBASIC
25	n6	n17	26	1	0	X617	.	.	1	26	.	28	14	KEY_ARC BASIC
26	n7	n18	28	1	0	X718	.	.	0	0	.	32	15	KEY_ARC BASIC
27	n8	n18	24	1	0	X818	.	.	0	0	-3	33	20	LOWERBD NONBASIC
28	n9	n18	26	1	0	X918	.	.	1	26	0	34	21	UPPERBD NONBASIC
29	n7	n19	24	1	0	X719	.	.	0	0	.	35	15	KEY_ARC BASIC
30	n8	n19	23	1	0	X819	.	.	1	23	0	36	20	UPPERBD NONBASIC
31	n9	n19	22	1	0	X919	.	.	0	0	.	37	21	NONKEY ARC BASIC
32	t	n2	0	99999999	0	XT2	.	.	1	0	.	14	22	KEY_ARC BASIC
33	n7	n20	23	1	0	X720	.	.	0	0	-1	38	15	LOWERBD NONBASIC
34	n8	n20	23	1	0	X820	.	.	0	0	.	39	20	KEY_ARC BASIC
35	n9	n20	22	1	0	X920	.	.	1	22	.	40	21	NONKEY ARC BASIC
36	n7	n21	22	1	0	X721	.	.	1	22	.	41	15	KEY_ARC BASIC
37	n8	n21	19	1	0	X821	.	.	0	0	-2	42	20	LOWERBD NONBASIC
38	n9	n21	19	1	0	X921	.	.	0	0	-1	43	21	LOWERBD NONBASIC
39	t	n3	0	99999999	0	XT3	.	.	2	0	.	15	22	KEY_ARC BASIC
40	t	n4	0	99999999	0	XT4	.	.	1	0	.	16	22	KEY_ARC BASIC
41	t	n5	0	99999999	0	XT5	.	.	1	0	.	29	22	KEY_ARC BASIC
42	t	n6	0	99999999	0	XT6	.	.	2	0	.	30	22	KEY_ARC BASIC
43	t	n7	0	99999999	0	XT7	.	.	1	0	.	31	22	KEY_ARC BASIC
44	t	n8	0	99999999	0	XT8	.	.	1	0	.	44	22	KEY_ARC BASIC
45	t	n9	0	99999999	0	XT9	.	.	2	0	.	45	22	KEY_ARC BASIC
46	n10	t	0	1	0	X10T	.	D	1	0	4	46	2	UPPERBD NONBASIC
47	n11	t	0	1	0	X11T	.	D	1	0	.	47	3	NONKEY ARC BASIC
48	n12	t	0	1	0	X12T	.	D	1	0	3	48	4	UPPERBD NONBASIC
49	n13	t	0	1	0	X13T	.	D	1	0	2	49	5	UPPERBD NONBASIC
50	n14	t	0	1	0	X14T	.	D	1	0	.	50	9	NONKEY ARC BASIC
51	n15	t	0	1	0	X15T	.	D	1	0	6	51	10	UPPERBD NONBASIC
52	n16	t	0	1	0	X16T	.	D	1	0	4	52	11	UPPERBD NONBASIC
53	n17	t	0	1	0	X17T	.	D	1	0	4	53	12	UPPERBD NONBASIC
54	n18	t	0	1	0	X18T	.	D	1	0	71	54	16	UPPERBD NONBASIC
55	n19	t	0	1	0	X19T	.	D	1	0	67	55	17	UPPERBD NONBASIC
56	n20	t	0	1	0	X20T	.	D	1	0	67	56	18	UPPERBD NONBASIC
57	n21	t	0	1	0	X21T	.	D	1	0	65	57	19	UPPERBD NONBASIC
										=======				
										295				

Appendix M. *NWSC Multi-Commodity Flow Formulation 2*

M.1 Formulation

```
options linesize=120;
options pagesize=66;
title 'Facility Location - run 9';
title3 'Nodes for Facility Location';
   data noded;
      input _node_ $ _sd_;
      cards;
   n1 0
   n2 0
   n3 0
   n4 0
   n5 0
   n6 0
   n7 0
   n8 0
   n9 0
   t  0
;

title3 'Arcs for Facility Location';
   data arcd1;
      input _from_ $ _to_ $ _cost_ _capac_ _name_ $;
      cards;
   n1  n10 20 1  x110
   n1  n11 22 1  x111
   n1  n12 24 1  x112
   n1  n13 21 1  x113
   n2  n10 23 1  x210
   n2  n11 19 1  x211
   n2  n12 28 1  x212
   n2  n13 22 1  x213
   n3  n10 27 1  x310
   n3  n11 23 1  x311
   n3  n12 21 1  x312
   n3  n13 25 1  x313
   n4  n14 21 1  x414
   n4  n15 27 1  x415
   n4  n16 25 1  x416
   n4  n17 21 1  x417
   n5  n14 21 1  x514
   n5  n15 23 1  x515
   n5  n16 23 1  x516
   n5  n17 23 1  x517
   n6  n14 19 1  x614
   n6  n15 28 1  x615
```

```
   n6  n16 26 1  x616
   n6  n17 26 1  x617
   n7  n18 28 1  x718
   n7  n19 24 1  x719
   n7  n20 23 1  x720
   n7  n21 22 1  x721
   n8  n18 24 1  x818
   n8  n19 23 1  x819
   n8  n20 23 1  x820
   n8  n21 19 1  x821
   n9  n18 26 1  x918
   n9  n19 22 1  x919
   n9  n20 22 1  x920
   n9  n21 19 1  x921
   n10 t   0  1  x10t
   n11 t   0  1  x11t
   n12 t   0  1  x12t
   n13 t   0  1  x13t
   n14 t   0  1  x14t
   n15 t   0  1  x15t
   n16 t   0  1  x16t
   n17 t   0  1  x17t
   n18 t   0  1  x18t
   n19 t   0  1  x19t
   n20 t   0  1  x20t
   n21 t   0  1  x21t
   t   n1  0  .  xt1
   t   n2  0  .  xt2
   t   n3  0  .  xt3
   t   n4  0  .  xt4
   t   n5  0  .  xt5
   t   n6  0  .  xt6
   t   n7  0  .  xt7
   t   n8  0  .  xt8
   t   n9  0  .  xt9
;

title3 'Side constraints';
data cond1;
   input
   x110 x111 x112 x113 x210 x211 x212 x213 x310 x311 x312 x313 x414 x415 x416
   x417 x514 x515 x516 x517 x614 x615 x616 x617 x718 x719 x720 x721 x818 x819
   x820 x821 x918 x919 x920 x921 xt1 xt2 xt3 xt4 xt5 xt6 xt7 xt8 xt9
   _type_ $ _rhs_;
   cards;

. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  -1 . . 1 . . . . . eq 0
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  -1 . . . . . 1 . . eq 0
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . -1 . . 1 . . . . eq 0
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . -1 . . . . . 1 . eq 0
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . -1 . . 1 . . . eq 0
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . -1 . . . . . 1 eq 0
-1 . . .  . . . .  . . . .  1 . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . eq 0
```

```
-1 . . .   . . . .   . . . .   . . . .   . . . .   . . . .   1 . . .   . . . .   . . . .   .  .  .  . . . . . . eq 0
. -1 . .   . . . .   . . . .   . 1 . .   . . . .   . . . .   . . . .   . . . .   . . . .   .  .  .  . . . . . . eq 0
. -1 . .   . . . .   . . . .   . . . .   . . . .   . . . .   . 1 . .   . . . .   . . . .   .  .  .  . . . . . . eq 0
. . -1 .   . . . .   . . . .   . . 1 .   . . . .   . . . .   . . . .   . . . .   . . . .   .  .  .  . . . . . . eq 0
. . -1 .   . . . .   . . . .   . . . .   . . . .   . . . .   . . 1 .   . . . .   . . . .   .  .  .  . . . . . . eq 0
. . . -1   . . . .   . . . .   . . . 1   . . . .   . . . .   . . . .   . . . .   . . . .   .  .  .  . . . . . . eq 0
. . . -1   . . .     . . . .   . . . .   . . . .   . . . .   . . . 1   . . . .   . . . .   .  .  .  . . . . . . eq 0
. . . .   -1 . . .   . . . .   . . . .   1 . . .   . . . .   . . . .   . . . .   . . . .   .  .  .  . . . . . . eq 0
. . . .   -1 . . .   . . . .   . . . .   . . . .   . . . .   . . . .   1 . . .   . . . .   .  .  .  . . . . . . eq 0
. . . .   . -1 . .   . . . .   . . . .   . 1 . .   . . . .   . . . .   . . . .   . . . .   .  .  .  . . . . . . eq 0
. . . .   . -1 . .   . . . .   . . . .   . . . .   . . . .   . . . .   . 1 . .   . . . .   .  .  .  . . . . . . eq 0
. . . .   . . -1 .   . . . .   . . . .   . . 1 .   . . . .   . . . .   . . . .   . . . .   .  .  .  . . . . . . eq 0
. . . .   . . -1 .   . . . .   . . . .   . . . .   . . . .   . . . .   . . 1 .   . . . .   .  .  .  . . . . . . eq 0
. . . .   . . . -1   . . . .   . . . .   . . . 1   . . . .   . . . .   . . . .   . . . .   .  .  .  . . . . . . eq 0
. . . .   . . . -1   . . . .   . . . .   . . . .   . . . .   . . . .   . . . 1   . . . .   .  .  .  . . . . . . eq 0
. . . .   . . . .   -1 . . .   . . . .   . . . .   1 . . .   . . . .   . . . .   . . . .   .  .  .  . . . . . . eq 0
. . . .   . . . .   -1 . . .   . . . .   . . . .   . . . .   . . . .   . . . .   1 . . .   .  .  .  . . . . . . eq 0
. . . .   . . . .   . -1 . .   . . . .   . . . .   . 1 . .   . . . .   . . . .   . . . .   .  .  .  . . . . . . eq 0
. . . .   . . . .   . -1 . .   . . . .   . . . .   . . . .   . . . .   . . . .   . 1 . .   .  .  .  . . . . . . eq 0
. . . .   . . . .   . . -1 .   . . . .   . . . .   . . 1 .   . . . .   . . . .   . . . .   .  .  .  . . . . . . eq 0
. . . .   . . . .   . . -1 .   . . . .   . . . .   . . . .   . . . .   . . . .   . . 1 .   .  .  .  . . . . . . eq 0
. . . .   . . . .   . . . -1   . . . .   . . . .   . . . 1   . . . .   . . . .   . . . .   .  .  .  . . . . . . eq 0
. . . .   . . . .   . . . -1   . . . .   . . . .   . . . .   . . . .   . . . .   . . . 1   .  .  .  . . . . . . eq 0
;


proc netflow
  nodedata=noded
  arcdata=arcd1
  condata=cond1
  conout=solution
  max
  sourcenode=s
  sinknode=t
  namectrl=1;

proc print data=solution;
sum _fcost_;
```

M.2 Solution

OBS	_FROM_	_TO_	_COST_	_CAPAC_	_LO_	_NAME_	_SUPPLY_	_DEMAND_	_FLOW_	_FCOST_	_RCOST_	_ANUMB_	_TNUMB_	_STATUS_
1	t	n1	0	99999999	0	XT1	.	.	0	0	.	1	22	KEY_ARC BASIC
2	n1	n10	20	1	0	X110	.	.	0	0	-3	2	1	LOWERBD NONBASIC
3	n2	n10	23	1	0	X210	.	.	0	0	-1	3	6	LOWERBD NONBASIC
4	n3	n10	27	1	0	X310	.	.	1	27	.	4	7	KEY_ARC BASIC
5	n1	n11	22	1	0	X111	.	.	0	0	.	5	1	NONKEY ARC BASIC
6	n2	n11	19	1	0	X211	.	.	0	0	-2	6	6	LOWERBD NONBASIC
7	n3	n11	23	1	0	X311	.	.	1	23	.	7	7	KEY_ARC BASIC
8	n1	n12	24	1	0	X112	.	.	0	0	.	8	1	NONKEY ARC BASIC
9	n2	n12	28	1	0	X212	.	.	1	28	.	9	6	KEY_ARC BASIC
10	n3	n12	21	1	0	X312	.	.	0	0	-2	10	7	LOWERBD NONBASIC
11	n1	n13	21	1	0	X113	.	.	0	0	0	11	1	LOWERBD NONBASIC
12	n2	n13	22	1	0	X213	.	.	0	0	.	12	6	NONKEY ARC BASIC
13	n3	n13	25	1	0	X313	.	.	1	25	.	13	7	KEY_ARC BASIC
14	n4	n14	21	1	0	X414	.	.	0	0	.	17	8	KEY_ARC BASIC
15	n5	n14	21	1	0	X514	.	.	0	0	-1	18	13	LOWERBD NONBASIC
16	n6	n14	19	1	0	X614	.	.	1	19	.	19	14	NONKEY ARC BASIC
17	n4	n15	27	1	0	X415	.	.	0	0	0	20	8	LOWERBD NONBASIC
18	n5	n15	23	1	0	X515	.	.	0	0	-6	21	13	LOWERBD NONBASIC
19	n6	n15	28	1	0	X615	.	.	1	28	.	22	14	KEY_ARC BASIC
20	n4	n16	25	1	0	X416	.	.	0	0	.	23	8	NONKEY ARC BASIC
21	n5	n16	23	1	0	X516	.	.	1	23	2	24	13	UPPERBD NONBASIC
22	n6	n16	26	1	0	X616	.	.	0	0	.	25	14	KEY_ARC BASIC
23	n4	n17	21	1	0	X417	.	.	0	0	-6	26	8	LOWERBD NONBASIC
24	n5	n17	23	1	0	X517	.	.	0	0	-6	27	13	LOWERBD NONBASIC
25	n6	n17	26	1	0	X617	.	.	1	26	.	28	14	KEY_ARC BASIC
26	n7	n18	28	1	0	X718	.	.	0	0	.	32	15	KEY_ARC BASIC
27	n8	n18	24	1	0	X818	.	.	0	0	-2	33	20	LOWERBD NONBASIC
28	n9	n18	26	1	0	X918	.	.	1	26	.	34	21	NONKEY ARC BASIC
29	n7	n19	24	1	0	X719	.	.	0	0	.	35	15	KEY_ARC BASIC
30	n8	n19	23	1	0	X819	.	.	0	0	.	36	20	NONKEY ARC BASIC
31	n9	n19	22	1	0	X919	.	.	1	22	.	37	21	NONKEY ARC BASIC
32	t	n2	0	99999999	0	XT2	.	.	1	0	.	14	22	KEY_ARC BASIC
33	n7	n20	23	1	0	X720	.	.	0	0	.	38	15	KEY_ARC BASIC
34	n8	n20	23	1	0	X820	.	.	1	23	.	39	20	KEY_ARC BASIC
35	n9	n20	22	1	0	X920	.	.	0	0	-1	40	21	LOWERBD NONBASIC
36	n7	n21	22	1	0	X721	.	.	0	0	.	41	15	KEY_ARC BASIC
37	n8	n21	19	1	0	X821	.	.	0	0	.	42	20	NONKEY ARC BASIC
38	n9	n21	19	1	0	X921	.	.	1	19	.	43	21	NONKEY ARC BASIC
39	t	n3	0	99999999	0	XT3	.	.	3	0	.	15	22	KEY_ARC BASIC
40	t	n4	0	99999999	0	XT4	.	.	0	0	.	16	22	KEY_ARC BASIC
41	t	n5	0	99999999	0	XT5	.	.	1	0	.	29	22	KEY_ARC BASIC
42	t	n6	0	99999999	0	XT6	.	.	3	0	.	30	22	KEY_ARC BASIC
43	t	n7	0	99999999	0	XT7	.	.	0	0	.	31	22	KEY_ARC BASIC
44	t	n8	0	99999999	0	XT8	.	.	1	0	.	44	22	NONKEY ARC BASIC
45	t	n9	0	99999999	0	XT9	.	.	3	0	.	45	22	NONKEY ARC BASIC
46	n10	t	0	1	0	X10T	.	D	1	0	2	46	2	UPPERBD NONBASIC
47	n11	t	0	1	0	X11T	.	D	1	0	.	47	3	NONKEY ARC BASIC
48	n12	t	0	1	0	X12T	.	D	1	0	68	48	4	UPPERBD NONBASIC
49	n13	t	0	1	0	X13T	.	D	1	0	.	49	5	NONKEY ARC BASIC
50	n14	t	0	1	0	X14T	.	D	1	0	63	50	9	UPPERBD NONBASIC
51	n15	t	0	1	0	X15T	.	D	1	0	70	51	10	UPPERBD NONBASIC
52	n16	t	0	1	0	X16T	.	D	1	0	.	52	11	NONKEY ARC BASIC
53	n17	t	0	1	0	X17T	.	D	1	0	70	53	12	UPPERBD NONBASIC
54	n18	t	0	1	0	X18T	.	D	1	0	7	54	16	UPPERBD NONBASIC
55	n19	t	0	1	0	X19T	.	D	1	0	3	55	17	UPPERBD NONBASIC
56	n20	t	0	1	0	X20T	.	D	1	0	4	56	18	UPPERBD NONBASIC
57	n21	t	0	1	0	X21T	.	D	1	0	.	57	19	NONKEY ARC BASIC
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										289				

Appendix N. *NWSC Multi-Commodity Flow Formulation 2 Reduced*

N.1 Formulation

```
options linesize=120;
options pagesize=66;
title 'Facility Location - run 9a';
title3 'Nodes for Facility Location';
   data noded;
      input _node_ $ _sd_;
      cards;
   n1 0
   n2 0
   n3 0
   n4 0
   n5 0
   n6 0
   n7 0
   n8 0
   n9 0
   t  0
;

title3 'Arcs for Facility Location';
   data arcd1;
      input _from_ $ _to_ $ _cost_ _capac_ _name_ $;
      cards;
   n1  n10 20 1  x110
   n1  n11 22 1  x111
   n1  n12 24 1  x112
   n1  n13 21 1  x113
   n2  n10 23 1  x210
   n2  n11 19 1  x211
   n2  n12 28 1  x212
   n2  n13 22 1  x213
   n3  n10 27 1  x310
   n3  n11 23 1  x311
   n3  n12 21 1  x312
   n3  n13 25 1  x313
   n4  n14 21 1  x414
   n4  n15 27 1  x415
   n4  n16 25 1  x416
   n4  n17 21 1  x417
   n5  n14 21 1  x514
   n5  n15 23 1  x515
   n5  n16 23 1  x516
   n5  n17 23 1  x517
   n6  n14 19 1  x614
   n6  n15 28 1  x615
```

```
   n6  n16 26 1  x616
   n6  n17 26 1  x617
   n7  n18 28 1  x718
   n7  n19 24 1  x719
   n7  n20 23 1  x720
   n7  n21 22 1  x721
   n8  n18 24 1  x818
   n8  n19 23 1  x819
   n8  n20 23 1  x820
   n8  n21 19 1  x821
   n9  n18 26 1  x918
   n9  n19 22 1  x919
   n9  n20 22 1  x920
   n9  n21 19 1  x921
   n10 t   0  1  x10t
   n11 t   0  1  x11t
   n12 t   0  1  x12t
   n13 t   0  1  x13t
   n14 t   0  1  x14t
   n15 t   0  1  x15t
   n16 t   0  1  x16t
   n17 t   0  1  x17t
   n18 t   0  1  x18t
   n19 t   0  1  x19t
   n20 t   0  1  x20t
   n21 t   0  1  x21t
   t   n1  0  .  xt1
   t   n2  0  .  xt2
   t   n3  0  .  xt3
   t   n4  0  .  xt4
   t   n5  0  .  xt5
   t   n6  0  .  xt6
   t   n7  0  .  xt7
   t   n8  0  .  xt8
   t   n9  0  .  xt9
;

title3 'Side constraints';
data cond1;
   input
   x110 x111 x112 x113 x210 x211 x212 x213 x310 x311 x312 x313 x414 x415 x416
   x417 x514 x515 x516 x517 x614 x615 x616 x617 x718 x719 x720 x721 x818 x819
   x820 x821 x918 x919 x920 x921 xt1 xt2 xt3 xt4 xt5 xt6 xt7 xt8 xt9
   _type_ $ _rhs_;
   cards;

. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . . . . -1 . . 1 . . . . . eq 0
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . . . . -1 . . . . . 1 . . eq 0
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . . . . . -1 . . 1 . . . . eq 0
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . . . . . -1 . . . . . 1 . eq 0
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . . . . . . -1 . . 1 . . . eq 0
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . . . . . . -1 . . . . . 1 eq 0
-1 . . .  . . . .  . . . .  1 . . .  . . . .  . . . .  . . . . . . . . . . . . . . . . . . . . . eq 0
```

```
-1 . . .  . . . .  . . . .  . . . .  . . . .  . . . .  1 . . .  . . . .  . . . .  . . .  . . . . . . eq 0
. -1 . .  . . . .  . . . .  . 1 . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . .  . . . . . . eq 0
. -1 . .  . . . .  . . . .  . . . .  . . . .  . . . .  . 1 . .  . . . .  . . . .  . . .  . . . . . . eq 0
. . -1 .  . . . .  . . . .  . . 1 .  . . . .  . . . .  . . . .  . . . .  . . . .  . . .  . . . . . . eq 0
. . -1 .  . . . .  . . . .  . . . .  . . . .  . . . .  . . 1 .  . . . .  . . . .  . . .  . . . . . . eq 0
. . . -1  . . . .  . . . .  . . . 1  . . . .  . . . .  . . . .  . . . .  . . . .  . . .  . . . . . . eq 0
. . . -1  . . . .  . . . .  . . . .  . . . .  . . . .  . . . 1  . . . .  . . . .  . . .  . . . . . . eq 0
. . . .  -1 . . .  . . . .  . . . .  1 . . .  . . . .  . . . .  . . . .  . . . .  . . .  . . . . . . eq 0
. . . .  -1 . . .  . . . .  . . . .  . . . .  . . . .  . . . .  1 . . .  . . . .  . . .  . . . . . . eq 0
. . . .  . -1 . .  . . . .  . . . .  . 1 . .  . . . .  . . . .  . . . .  . . . .  . . .  . . . . . . eq 0
. . . .  . -1 . .  . . . .  . . . .  . . . .  . . . .  . . . .  . 1 . .  . . . .  . . .  . . . . . . eq 0
. . . .  . . -1 .  . . . .  . . . .  . . 1 .  . . . .  . . . .  . . . .  . . . .  . . .  . . . . . . eq 0
. . . .  . . -1 .  . . . .  . . . .  . . . .  . . . .  . . . .  . . 1 .  . . . .  . . .  . . . . . . eq 0
. . . .  . . . -1  . . . .  . . . .  . . . 1  . . . .  . . . .  . . . .  . . . .  . . .  . . . . . . eq 0
. . . .  . . . -1  . . . .  . . . .  . . . .  . . . .  . . . .  . . . 1  . . . .  . . .  . . . . . . eq 0
;

proc netflow
  nodedata=noded
  arcdata=arcd1
  condata=cond1
  conout=solution
  max
  sourcenode=s
  sinknode=t
  namectrl=1;

proc print data=solution;
sum _fcost_;
```

N.2 Solution

OBS	_FROM_	_TO_	_COST_	_CAPAC_	_LO_	_NAME_	_SUPPLY_	_DEMAND_	_FLOW_	_FCOST_	_RCOST_	_ANUMB_	_TNUMB_	_STATUS_
1	t	n1	0	99999999	0	XT1	.	.	0	0	.	1	22	KEY_ARC BASIC
2	n1	n10	20	1	0	X110	.	.	0	0	-3	2	1	LOWERBD NONBASIC
3	n2	n10	23	1	0	X210	.	.	0	0	-1	3	6	LOWERBD NONBASIC
4	n3	n10	27	1	0	X310	.	.	1	27	.	4	7	KEY_ARC BASIC
5	n1	n11	22	1	0	X111	.	.	0	0	.	5	1	NONKEY ARC BASIC
6	n2	n11	19	1	0	X211	.	.	0	0	-2	6	6	LOWERBD NONBASIC
7	n3	n11	23	1	0	X311	.	.	1	23	.	7	7	KEY_ARC BASIC
8	n1	n12	24	1	0	X112	.	.	0	0	.	8	1	NONKEY ARC BASIC
9	n2	n12	28	1	0	X212	.	.	1	28	.	9	6	KEY_ARC BASIC
10	n3	n12	21	1	0	X312	.	.	0	0	-2	10	7	LOWERBD NONBASIC
11	n1	n13	21	1	0	X113	.	.	0	0	0	11	1	LOWERBD NONBASIC
12	n2	n13	22	1	0	X213	.	.	0	0	.	12	6	NONKEY ARC BASIC
13	n3	n13	25	1	0	X313	.	.	1	25	.	13	7	KEY_ARC BASIC
14	n4	n14	21	1	0	X414	.	.	0	0	.	17	8	KEY_ARC BASIC
15	n5	n14	21	1	0	X514	.	.	0	0	-1	18	13	LOWERBD NONBASIC
16	n6	n14	19	1	0	X614	.	.	1	19	.	19	14	NONKEY ARC BASIC
17	n4	n15	27	1	0	X415	.	.	0	0	0	20	8	LOWERBD NONBASIC
18	n5	n15	23	1	0	X515	.	.	0	0	-6	21	13	LOWERBD NONBASIC
19	n6	n15	28	1	0	X615	.	.	1	28	.	22	14	KEY_ARC BASIC
20	n4	n16	25	1	0	X416	.	.	0	0	.	23	8	NONKEY ARC BASIC
21	n5	n16	23	1	0	X516	.	.	1	23	2	24	13	UPPERBD NONBASIC
22	n6	n16	26	1	0	X616	.	.	0	0	.	25	14	KEY_ARC BASIC
23	n4	n17	21	1	0	X417	.	.	0	0	-6	26	8	LOWERBD NONBASIC
24	n5	n17	23	1	0	X517	.	.	0	0	-6	27	13	LOWERBD NONBASIC
25	n6	n17	26	1	0	X617	.	.	1	26	.	28	14	KEY_ARC BASIC
26	n7	n18	28	1	0	X718	.	.	0	0	.	32	15	KEY_ARC BASIC
27	n8	n18	24	1	0	X818	.	.	0	0	-2	33	20	LOWERBD NONBASIC
28	n9	n18	26	1	0	X918	.	.	1	26	.	34	21	NONKEY ARC BASIC
29	n7	n19	24	1	0	X719	.	.	0	0	.	35	15	KEY_ARC BASIC
30	n8	n19	23	1	0	X819	.	.	0	0	.	36	20	NONKEY ARC BASIC
31	n9	n19	22	1	0	X919	.	.	1	22	.	37	21	NONKEY ARC BASIC
32	t	n2	0	99999999	0	XT2	.	.	1	0	.	14	22	KEY_ARC BASIC
33	n7	n20	23	1	0	X720	.	.	0	0	.	38	15	KEY_ARC BASIC
34	n8	n20	23	1	0	X820	.	.	1	23	.	39	20	KEY_ARC BASIC
35	n9	n20	22	1	0	X920	.	.	0	0	-1	40	21	LOWERBD NONBASIC
36	n7	n21	22	1	0	X721	.	.	0	0	.	41	15	KEY_ARC BASIC
37	n8	n21	19	1	0	X821	.	.	0	0	.	42	20	NONKEY ARC BASIC
38	n9	n21	19	1	0	X921	.	.	1	19	.	43	21	NONKEY ARC BASIC
39	t	n3	0	99999999	0	XT3	.	.	3	0	.	15	22	KEY_ARC BASIC
40	t	n4	0	99999999	0	XT4	.	.	0	0	.	16	22	KEY_ARC BASIC
41	t	n5	0	99999999	0	XT5	.	.	1	0	.	29	22	KEY_ARC BASIC
42	t	n6	0	99999999	0	XT6	.	.	3	0	.	30	22	KEY_ARC BASIC
43	t	n7	0	99999999	0	XT7	.	.	0	0	.	31	22	KEY_ARC BASIC
44	t	n8	0	99999999	0	XT8	.	.	1	0	.	44	22	NONKEY ARC BASIC
45	t	n9	0	99999999	0	XT9	.	.	3	0	.	45	22	NONKEY ARC BASIC
46	n10	t	0	1	0	X10T	.	D	1	0	2	46	2	UPPERBD NONBASIC
47	n11	t	0	1	0	X11T	.	D	1	0	.	47	3	NONKEY ARC BASIC
48	n12	t	0	1	0	X12T	.	D	1	0	68	48	4	UPPERBD NONBASIC
49	n13	t	0	1	0	X13T	.	D	1	0	.	49	5	NONKEY ARC BASIC
50	n14	t	0	1	0	X14T	.	D	1	0	63	50	9	UPPERBD NONBASIC
51	n15	t	0	1	0	X15T	.	D	1	0	70	51	10	UPPERBD NONBASIC
52	n16	t	0	1	0	X16T	.	D	1	0	.	52	11	NONKEY ARC BASIC
53	n17	t	0	1	0	X17T	.	D	1	0	70	53	12	UPPERBD NONBASIC
54	n18	t	0	1	0	X18T	.	D	1	0	7	54	16	UPPERBD NONBASIC
55	n19	t	0	1	0	X19T	.	D	1	0	3	55	17	UPPERBD NONBASIC
56	n20	t	0	1	0	X20T	.	D	1	0	4	56	18	UPPERBD NONBASIC
57	n21	t	0	1	0	X21T	.	D	1	0	.	57	19	NONKEY ARC BASIC
										=======				
										289				

Appendix O. *NWSC Multi-Commodity Flow Formulation 3*

O.1 Formulation

```
options linesize=120;
options pagesize=66;
title 'Facility Location - run 10';
title3 'Nodes for Facility Location';
   data noded;
      input _node_ $ _sd_;
      cards;
   s  0
   n4 0
   n5 0
   n6 0
   n7 0
   n8 0
   n9 0
   t  0
;

title3 'Arcs for Facility Location';
   data arcd1;
      input _from_ $ _to_ $ _cost_ _capac_ _name_ $;
      cards;
   s   n1   0 4  xs1
   s   n2   0 4  xs2
   s   n3   0 4  xs3
   n1  n10 20 1  x110
   n1  n11 22 1  x111
   n1  n12 24 1  x112
   n1  n13 21 1  x113
   n2  n10 23 1  x210
   n2  n11 19 1  x211
   n2  n12 26 1  x212
   n2  n13 22 1  x213
   n3  n10 27 1  x310
   n3  n11 23 1  x311
   n3  n12 21 1  x312
   n3  n13 25 1  x313
   n4  n14 21 1  x414
   n4  n15 27 1  x415
   n4  n16 25 1  x416
   n4  n17 21 1  x417
   n5  n14 21 1  x514
   n5  n15 23 1  x515
   n5  n16 23 1  x516
   n5  n17 23 1  x517
   n6  n14 19 1  x614
```

```
   n6  n15 28 1  x615
   n6  n16 26 1  x616
   n6  n17 26 1  x617
   n7  n18 28 1  x718
   n7  n19 24 1  x719
   n7  n20 23 1  x720
   n7  n21 22 1  x721
   n8  n18 24 1  x818
   n8  n19 23 1  x819
   n8  n20 23 1  x820
   n8  n21 19 1  x821
   n9  n18 26 1  x918
   n9  n19 22 1  x919
   n9  n20 22 1  x920
   n9  n21 19 1  x921
   n10 t   0  1  x10t
   n11 t   0  1  x11t
   n12 t   0  1  x12t
   n13 t   0  1  x13t
   n14 t   0  1  x14t
   n15 t   0  1  x15t
   n16 t   0  1  x16t
   n17 t   0  1  x17t
   n18 t   0  1  x18t
   n19 t   0  1  x19t
   n20 t   0  1  x20t
   n21 t   0  1  x21t
   t   s   0  .  xts
   t   n4  0  .  xt4
   t   n5  0  .  xt5
   t   n6  0  .  xt6
   t   n7  0  .  xt7
   t   n8  0  .  xt8
   t   n9  0  .  xt9
;

title3 'Side constraints';
data cond1;
   input
   x110 x111 x112 x113 x210 x211 x212 x213 x310 x311 x312 x313 x414 x415 x416
   x417 x514 x515 x516 x517 x614 x615 x616 x617 x718 x719 x720 x721 x818 x819
   x820 x821 x918 x919 x920 x921 xts xs1 xs2 xs3 xt4 xt5 xt6 xt7 xt8 xt9
   _type_ $ _rhs_;
   cards;

4 . . .  . 4 . .  . . 4 .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  -1  . . . . . . . . .  le 0
4 . . .  . 4 . .  . . . 4  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  -1  . . . . . . . . .  le 0
. 4 . .  . . 4 .  . . . 4  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  -1  . . . . . . . . .  le 0
. 4 . .  . . . 4  . . 4 .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  -1  . . . . . . . . .  le 0
. 4 . .  4 . . .  . . . 4  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  -1  . . . . . . . . .  le 0
. 4 . .  4 . . .  . . 4 .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  -1  . . . . . . . . .  le 0
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .   .  -1 . . 1 . . . . .  eq 0
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .   .  -1 . . . . . 1 . .  eq 0
```

```
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . -1 . . 1 . . . . eq 0
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . -1 . . . . . 1 . eq 0
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . -1 . . 1 . . . eq 0
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . -1 . . . . . 1 eq 0
-1 . . .  . . . .  . . . .  1 . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . . eq 0
-1 . . .  . . . .  . . . .  . . . .  . . . .  . . . .  1 . . .  . . . .  . . . .  . . . . . . . . . . eq 0
. -1 . .  . . . .  . . . .  . 1 . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . . eq 0
. -1 . .  . . . .  . . . .  . . . .  . . . .  . . . .  . 1 . .  . . . .  . . . .  . . . . . . . . . . eq 0
. . -1 .  . . . .  . . . .  . . 1 .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . . eq 0
. . -1 .  . . . .  . . . .  . . . .  . . . .  . . . .  . . 1 .  . . . .  . . . .  . . . . . . . . . . eq 0
. . . -1  . . . .  . . . .  . . . 1  . . . .  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . . eq 0
. . . -1  . . . .  . . . .  . . . .  . . . .  . . . .  . . . 1  . . . .  . . . .  . . . . . . . . . . eq 0
. . . .  -1 . . .  . . . .  . . . .  1 . . .  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . . eq 0
. . . .  -1 . . .  . . . .  . . . .  . . . .  . . . .  . . . .  1 . . .  . . . .  . . . . . . . . . . eq 0
. . . .  . -1 . .  . . . .  . . . .  . 1 . .  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . . eq 0
. . . .  . -1 . .  . . . .  . . . .  . . . .  . . . .  . . . .  . 1 . .  . . . .  . . . . . . . . . . eq 0
. . . .  . . -1 .  . . . .  . . . .  . . 1 .  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . . eq 0
. . . .  . . -1 .  . . . .  . . . .  . . . .  . . . .  . . . .  . . 1 .  . . . .  . . . . . . . . . . eq 0
. . . .  . . . -1  . . . .  . . . .  . . . 1  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . . eq 0
. . . .  . . . -1  . . . .  . . . .  . . . .  . . . .  . . . .  . . . 1  . . . .  . . . . . . . . . . eq 0
. . . .  . . . .  -1 . . .  . . . .  . . . .  1 . . .  . . . .  . . . .  . . . .  . . . . . . . . . . eq 0
. . . .  . . . .  -1 . . .  . . . .  . . . .  . . . .  . . . .  . . . .  1 . . .  . . . . . . . . . . eq 0
. . . .  . . . .  . -1 . .  . . . .  . . . .  . 1 . .  . . . .  . . . .  . . . .  . . . . . . . . . . eq 0
. . . .  . . . .  . -1 . .  . . . .  . . . .  . . . .  . . . .  . . . .  . 1 . .  . . . . . . . . . . eq 0
. . . .  . . . .  . . -1 .  . . . .  . . . .  . . 1 .  . . . .  . . . .  . . . .  . . . . . . . . . . eq 0
. . . .  . . . .  . . -1 .  . . . .  . . . .  . . . .  . . . .  . . . .  . . 1 .  . . . . . . . . . . eq 0
. . . .  . . . .  . . . -1  . . . .  . . . .  . . . 1  . . . .  . . . .  . . . .  . . . . . . . . . . eq 0
. . . .  . . . .  . . . -1  . . . .  . . . .  . . . .  . . . .  . . . .  . . . 1  . . . . . . . . . . eq 0
;


proc netflow
  nodedata=noded
  arcdata=arcd1
  condata=cond1
  conout=solution
  max
  sourcenode=s
  sinknode=t
  namectrl=1;

proc print data=solution;
sum _fcost_;
```

O.2 Solution

OBS	_FROM_	_TO_	_COST_	_CAPAC_	_LO_	_NAME_	_SUPPLY_	_DEMAND_	_FLOW_	_FCOST_	_RCOST_	_ANUMB_	_TNUMB_	_STATUS_
1	s	n1	0	4	0	XS1	.	.	0	0	.	2	1	KEY_ARC BASIC
2	n1	n10	20	1	0	X110	.	.	0	0	.	5	2	NONKEY ARC BASIC
3	n2	n10	23	1	0	X210	.	.	0	0	.	6	3	NONKEY ARC BASIC
4	n3	n10	27	1	0	X310	.	.	1	27	.	7	4	KEY_ARC BASIC
5	n1	n11	22	1	0	X111	.	.	0	0	.	8	2	NONKEY ARC BASIC
6	n2	n11	19	1	0	X211	.	.	0	0	.	9	3	NONKEY ARC BASIC
7	n3	n11	23	1	0	X311	.	.	1	23	.	10	4	KEY_ARC BASIC
8	n1	n12	24	1	0	X112	.	.	0	0	.	11	2	NONKEY ARC BASIC
9	n2	n12	26	1	0	X212	.	.	0	0	.	12	3	KEY_ARC BASIC
10	n3	n12	21	1	0	X312	.	.	1	21	.	13	4	NONKEY ARC BASIC
11	n1	n13	21	1	0	X113	.	.	0	0	.	14	2	NONKEY ARC BASIC
12	n2	n13	22	1	0	X213	.	.	0	0	.	15	3	NONKEY ARC BASIC
13	n3	n13	25	1	0	X313	.	.	1	25	.	16	4	KEY_ARC BASIC
14	n4	n14	21	1	0	X414	.	.	0	0	.	18	9	KEY_ARC BASIC
15	n5	n14	21	1	0	X514	.	.	0	0	-4.0	19	14	LOWERBD NONBASIC
16	n6	n14	19	1	0	X614	.	.	1	19	3.0	20	15	UPPERBD NONBASIC
17	n4	n15	27	1	0	X415	.	.	0	0	-2.0	21	9	LOWERBD NONBASIC
18	n5	n15	23	1	0	X515	.	.	0	0	-7.0	22	14	LOWERBD NONBASIC
19	n6	n15	28	1	0	X615	.	.	1	28	.	23	15	KEY_ARC BASIC
20	n4	n16	25	1	0	X416	.	.	0	0	.	24	9	NONKEY ARC BASIC
21	n5	n16	23	1	0	X516	.	.	0	0	.	25	14	NONKEY ARC BASIC
22	n6	n16	26	1	0	X616	.	.	1	26	.	26	15	KEY_ARC BASIC
23	n4	n17	21	1	0	X417	.	.	0	0	0.0	27	9	LOWERBD NONBASIC
24	n5	n17	23	1	0	X517	.	.	0	0	.	28	14	NONKEY ARC BASIC
25	n6	n17	26	1	0	X617	.	.	1	26	.	29	15	KEY_ARC BASIC
26	n7	n18	28	1	0	X718	.	.	0	0	.	33	16	KEY_ARC BASIC
27	n8	n18	24	1	0	X818	.	.	0	0	.	34	21	NONKEY ARC BASIC
28	n9	n18	26	1	0	X918	.	.	1	26	.	35	22	NONKEY ARC BASIC
29	n7	n19	24	1	0	X719	.	.	0	0	.	36	16	KEY_ARC BASIC
30	n8	n19	23	1	0	X819	.	.	0	0	.	37	21	NONKEY ARC BASIC
31	n9	n19	22	1	0	X919	.	.	1	22	1.0	38	22	UPPERBD NONBASIC
32	s	n2	0	4	0	XS2	.	.	0	0	.	3	1	KEY_ARC BASIC
33	n7	n20	23	1	0	X720	.	.	0	0	.	39	16	KEY_ARC BASIC
34	n8	n20	23	1	0	X820	.	.	0	0	.	40	21	KEY_ARC BASIC
35	n9	n20	22	1	0	X920	.	.	1	22	.	41	22	NONKEY ARC BASIC
36	n7	n21	22	1	0	X721	.	.	0	0	.	42	16	KEY_ARC BASIC
37	n8	n21	19	1	0	X821	.	.	0	0	.	43	21	NONKEY ARC BASIC
38	n9	n21	19	1	0	X921	.	.	1	19	.	44	22	NONKEY ARC BASIC
39	s	n3	0	4	0	XS3	.	.	4	0	.	4	1	KEY_ARC BASIC
40	t	n4	0	99999999	0	XT4	.	.	0	0	.	17	23	KEY_ARC BASIC
41	t	n5	0	99999999	0	XT5	.	.	0	0	.	30	23	KEY_ARC BASIC
42	t	n6	0	99999999	0	XT6	.	.	4	0	.	31	23	KEY_ARC BASIC
43	t	n7	0	99999999	0	XT7	.	.	0	0	.	32	23	NONKEY ARC BASIC
44	t	n8	0	99999999	0	XT8	.	.	0	0	.	45	23	KEY_ARC BASIC
45	t	n9	0	99999999	0	XT9	.	.	4	0	.	46	23	NONKEY ARC BASIC
46	t	s	0	99999999	0	XTS	.	.	4	0	.	1	23	KEY_ARC BASIC
47	n10	t	0	1	0	X10T	.	D	1	0	.	47	5	NONKEY ARC BASIC
48	n11	t	0	1	0	X11T	.	D	1	0	60.5	48	6	UPPERBD NONBASIC
49	n12	t	0	1	0	X12T	.	D	1	0	63.5	49	7	UPPERBD NONBASIC
50	n13	t	0	1	0	X13T	.	D	1	0	65.5	50	8	UPPERBD NONBASIC
51	n14	t	0	1	0	X14T	.	D	1	0	70.5	51	10	UPPERBD NONBASIC
52	n15	t	0	1	0	X15T	.	D	1	0	11.0	52	11	UPPERBD NONBASIC
53	n16	t	0	1	0	X16T	.	D	1	0	4.0	53	12	UPPERBD NONBASIC
54	n17	t	0	1	0	X17T	.	D	1	0	.	54	13	NONKEY ARC BASIC
55	n18	t	0	1	0	X18T	.	D	1	0	.	55	17	NONKEY ARC BASIC
56	n19	t	0	1	0	X19T	.	D	1	0	2.0	56	18	UPPERBD NONBASIC
57	n20	t	0	1	0	X20T	.	D	1	0	3.0	57	19	UPPERBD NONBASIC
58	n21	t	0	1	0	X21T	.	D	1	0	.	58	20	NONKEY ARC BASIC
										=======				
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Appendix P. *NWSC Multi-Commodity Flow Formulation 3 Reduced*

P.1 Formulation

```
options linesize=120;
options pagesize=66;
title 'Facility Location - run 11';
title3 'Nodes for Facility Location';
   data noded;
      input _node_ $ _sd_;
      cards;
   s  0
   n4 0
   n5 0
   n6 0
   n7 0
   n8 0
   n9 0
   t  0
;

title3 'Arcs for Facility Location';
   data arcd1;
      input _from_ $ _to_ $ _cost_ _capac_ _name_ $;
      cards;
   s   n1   0 4  xs1
   s   n2   0 4  xs2
   s   n3   0 4  xs3
   n1  n10 20 1  x110
   n1  n11 22 1  x111
   n1  n12 24 1  x112
   n1  n13 21 1  x113
   n2  n10 23 1  x210
   n2  n11 19 1  x211
   n2  n12 26 1  x212
   n2  n13 22 1  x213
   n3  n10 27 1  x310
   n3  n11 23 1  x311
   n3  n12 21 1  x312
   n3  n13 25 1  x313
   n4  n14 21 1  x414
   n4  n15 27 1  x415
   n4  n16 25 1  x416
   n4  n17 21 1  x417
   n5  n14 21 1  x514
   n5  n15 23 1  x515
   n5  n16 23 1  x516
   n5  n17 23 1  x517
   n6  n14 19 1  x614
```

```
   n6  n15 28 1  x615
   n6  n16 26 1  x616
   n6  n17 26 1  x617
   n7  n18 28 1  x718
   n7  n19 24 1  x719
   n7  n20 22 1  x720
   n7  n21 22 1  x721
   n8  n18 24 1  x818
   n8  n19 23 1  x819
   n8  n20 23 1  x820
   n8  n21 19 1  x821
   n9  n18 26 1  x918
   n9  n19 22 1  x919
   n9  n20 22 1  x920
   n9  n21 19 1  x921
   n10 t   0  1  x10t
   n11 t   0  1  x11t
   n12 t   0  1  x12t
   n13 t   0  1  x13t
   n14 t   0  1  x14t
   n15 t   0  1  x15t
   n16 t   0  1  x16t
   n17 t   0  1  x17t
   n18 t   0  1  x18t
   n19 t   0  1  x19t
   n20 t   0  1  x20t
   n21 t   0  1  x21t
   t   s   0  .  xts
   t   n4  0  .  xt4
   t   n5  0  .  xt5
   t   n6  0  .  xt6
   t   n7  0  .  xt7
   t   n8  0  .  xt8
   t   n9  0  .  xt9
;

title3 'Side constraints';
data cond1;
   input
   x110 x111 x112 x113 x210 x211 x212 x213 x310 x311 x312 x313 x414 x415 x416
   x417 x514 x515 x516 x517 x614 x615 x616 x617 x718 x719 x720 x721 x818 x819
   x820 x821 x918 x919 x920 x921 xts xs1 xs2 xs3 xt4 xt5 xt6 xt7 xt8 xt9
   _type_ $ _rhs_;
   cards;

4 . . .  . 4 . .  . . 4 .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  -1 . . . . . . . . . le 0
4 . . .  . 4 . .  . . . 4  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  -1 . . . . . . . . . le 0
. 4 . .  . . 4 .  . . . 4  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  -1 . . . . . . . . . le 0
. 4 . .  . . . 4  . . 4 .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  -1 . . . . . . . . . le 0
. 4 . .  4 . . .  . . . 4  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  -1 . . . . . . . . . le 0
. . 4 .  4 . . .  . . . 4  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  -1 . . . . . . . . . le 0
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . -1 . . 1 . . . . . eq 0
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . -1 . . . . . 1 . . eq 0
```

```
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . -1 . . 1 . . . . eq 0
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . -1 . . . . . 1 . eq 0
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . -1 . . 1 . . . eq 0
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . -1 . . . . . 1 eq 0
-1 . . .  . . . .  . . . .  1 . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . . eq 0
-1 . . .  . . . .  . . . .  . . . .  . . . .  . . . .  1 . . .  . . . .  . . . .  . . . . . . . . . . eq 0
. -1 . .  . . . .  . . . .  . 1 . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . . eq 0
. -1 . .  . . . .  . . . .  . . . .  . . . .  . . . .  . 1 . .  . . . .  . . . .  . . . . . . . . . . eq 0
. . -1 .  . . . .  . . . .  . . 1 .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . . eq 0
. . -1 .  . . . .  . . . .  . . . .  . . . .  . . . .  . . 1 .  . . . .  . . . .  . . . . . . . . . . eq 0
. . . -1  . . . .  . . . .  . . . 1  . . . .  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . . eq 0
. . . -1  . . . .  . . . .  . . . .  . . . .  . . . .  . . . 1  . . . .  . . . .  . . . . . . . . . . eq 0
. . . .  -1 . . .  . . . .  . . . .  1 . . .  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . . eq 0
. . . .  -1 . . .  . . . .  . . . .  . . . .  . . . .  . . . .  1 . . .  . . . .  . . . . . . . . . . eq 0
. . . .  . -1 . .  . . . .  . . . .  . 1 . .  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . . eq 0
. . . .  . -1 . .  . . . .  . . . .  . . . .  . . . .  . . . .  . 1 . .  . . . .  . . . . . . . . . . eq 0
. . . .  . . -1 .  . . . .  . . . .  . . 1 .  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . . eq 0
. . . .  . . -1 .  . . . .  . . . .  . . . .  . . . .  . . . .  . . 1 .  . . . .  . . . . . . . . . . eq 0
. . . .  . . . -1  . . . .  . . . .  . . . 1  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . . eq 0
. . . .  . . . -1  . . . .  . . . .  . . . .  . . . .  . . . .  . . . 1  . . . .  . . . . . . . . . . eq 0
;

proc netflow
  nodedata=noded
  arcdata=arcd1
  condata=cond1
  conout=solution
  max
  sourcenode=s
  sinknode=t
  namectrl=1;

proc print data=solution;
sum _fcost_;
```

P.2 Solution

OBS	_FROM_	_TO_	_COST_	_CAPAC_	_LO_	_NAME_	_SUPPLY_	_DEMAND_	_FLOW_	_FCOST_	_RCOST_	_ANUMB_	_TNUMB_	_STATUS_
1	s	n1	0	4	0	XS1	.	.	0	0	.	2	1	KEY_ARC BASIC
2	n1	n10	20	1	0	X110	.	.	0	0	-3.0	5	2	LOWERBD NONBASIC
3	n2	n10	23	1	0	X210	.	.	0	0	-6.5	6	3	LOWERBD NONBASIC
4	n3	n10	27	1	0	X310	.	.	1	27	.	7	4	KEY_ARC BASIC
5	n1	n11	22	1	0	X111	.	.	0	0	-3.5	8	2	LOWERBD NONBASIC
6	n2	n11	19	1	0	X211	.	.	0	0	-6.0	9	3	LOWERBD NONBASIC
7	n3	n11	23	1	0	X311	.	.	1	23	.	10	4	KEY_ARC BASIC
8	n1	n12	24	1	0	X112	.	.	0	0	.	11	2	NONKEY ARC BASIC
9	n2	n12	26	1	0	X212	.	.	0	0	.	12	3	KEY_ARC BASIC
10	n3	n12	21	1	0	X312	.	.	1	21	.	13	4	NONKEY ARC BASIC
11	n1	n13	21	1	0	X113	.	.	0	0	.	14	2	NONKEY ARC BASIC
12	n2	n13	22	1	0	X213	.	.	0	0	.	15	3	NONKEY ARC BASIC
13	n3	n13	25	1	0	X313	.	.	1	25	.	16	4	KEY_ARC BASIC
14	n4	n14	21	1	0	X414	.	.	0	0	.	18	9	KEY_ARC BASIC
15	n5	n14	21	1	0	X514	.	.	0	0	.	19	14	NONKEY ARC BASIC
16	n6	n14	19	1	0	X614	.	.	1	19	.	20	15	NONKEY ARC BASIC
17	n4	n15	27	1	0	X415	.	.	0	0	.	21	9	NONKEY ARC BASIC
18	n5	n15	23	1	0	X515	.	.	0	0	-2.0	22	14	LOWERBD NONBASIC
19	n6	n15	28	1	0	X615	.	.	1	28	.	23	15	KEY_ARC BASIC
20	n4	n16	25	1	0	X416	.	.	0	0	.	24	9	NONKEY ARC BASIC
21	n5	n16	23	1	0	X516	.	.	0	0	.	25	14	NONKEY ARC BASIC
22	n6	n16	26	1	0	X616	.	.	1	26	.	26	15	KEY_ARC BASIC
23	n4	n17	21	1	0	X417	.	.	0	0	.	27	9	NONKEY ARC BASIC
24	n5	n17	23	1	0	X517	.	.	0	0	.	28	14	NONKEY ARC BASIC
25	n6	n17	26	1	0	X617	.	.	1	26	.	29	15	KEY_ARC BASIC
26	n7	n18	28	1	0	X718	.	.	0	0	.	33	16	KEY_ARC BASIC
27	n8	n18	24	1	0	X818	.	.	0	0	.	34	21	NONKEY ARC BASIC
28	n9	n18	26	1	0	X918	.	.	1	26	.	35	22	NONKEY ARC BASIC
29	n7	n19	24	1	0	X719	.	.	0	0	.	36	16	KEY_ARC BASIC
30	n8	n19	23	1	0	X819	.	.	0	0	.	37	21	NONKEY ARC BASIC
31	n9	n19	22	1	0	X919	.	.	1	22	.	38	22	KEY_ARC BASIC
32	s	n2	0	4	0	XS2	.	.	0	0	.	3	1	KEY_ARC BASIC
33	n7	n20	22	1	0	X720	.	.	0	0	.	39	16	NONKEY ARC BASIC
34	n8	n20	23	1	0	X820	.	.	0	0	.	40	21	KEY_ARC BASIC
35	n9	n20	22	1	0	X920	.	.	1	22	0.5	41	22	UPPERBD NONBASIC
36	n7	n21	22	1	0	X721	.	.	0	0	.	42	16	KEY_ARC BASIC
37	n8	n21	19	1	0	X821	.	.	0	0	0.0	43	21	LOWERBD NONBASIC
38	n9	n21	19	1	0	X921	.	.	1	19	.	44	22	NONKEY ARC BASIC
39	s	n3	0	4	0	XS3	.	.	4	0	.	4	1	KEY_ARC BASIC
40	t	n4	0	99999999	0	XT4	.	.	0	0	.	17	23	KEY_ARC BASIC
41	t	n5	0	99999999	0	XT5	.	.	0	0	.	30	23	KEY_ARC BASIC
42	t	n6	0	99999999	0	XT6	.	.	4	0	.	31	23	KEY_ARC BASIC
43	t	n7	0	99999999	0	XT7	.	.	0	0	.	32	23	KEY_ARC BASIC
44	t	n8	0	99999999	0	XT8	.	.	0	0	.	45	23	KEY_ARC BASIC
45	t	n9	0	99999999	0	XT9	.	.	4	0	.	46	23	NONKEY ARC BASIC
46	t	s	0	99999999	0	XTS	.	.	4	0	.	1	23	KEY_ARC BASIC
47	n10	t	0	1	0	X10T	.	D	1	0	8.0	47	5	UPPERBD NONBASIC
48	n11	t	0	1	0	X11T	.	D	1	0	4.0	48	6	UPPERBD NONBASIC
49	n12	t	0	1	0	X12T	.	D	1	0	2.0	49	7	UPPERBD NONBASIC
50	n13	t	0	1	0	X13T	.	D	1	0	.	50	8	NONKEY ARC BASIC
51	n14	t	0	1	0	X14T	.	D	1	0	.	51	10	NONKEY ARC BASIC
52	n15	t	0	1	0	X15T	.	D	1	0	9.0	52	11	UPPERBD NONBASIC
53	n16	t	0	1	0	X16T	.	D	1	0	7.0	53	12	UPPERBD NONBASIC
54	n17	t	0	1	0	X17T	.	D	1	0	7.0	54	13	UPPERBD NONBASIC
55	n18	t	0	1	0	X18T	.	D	1	0	65.5	55	17	UPPERBD NONBASIC
56	n19	t	0	1	0	X19T	.	D	1	0	61.5	56	18	UPPERBD NONBASIC
57	n20	t	0	1	0	X20T	.	D	1	0	61.0	57	19	UPPERBD NONBASIC
58	n21	t	0	1	0	X21T	.	D	1	0	58.5	58	20	UPPERBD NONBASIC
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Appendix Q. *NWSC Multi-Commodity Flow Formulation 3 Reduced Further*

Q.1 Formulation

```
options linesize=120;
options pagesize=66;
title 'Facility Location - run 12';
title3 'Nodes for Facility Location';
   data noded;
      input _node_ $ _sd_;
      cards;
   s  0
   n4 0
   n5 0
   n6 0
   n7 0
   n8 0
   n9 0
   t  0
;

title3 'Arcs for Facility Location';
   data arcd1;
      input _from_ $ _to_ $ _cost_ _capac_ _name_ $;
      cards;
   s   n1   0 4  xs1
   s   n2   0 4  xs2
   s   n3   0 4  xs3
   n1  n10 20 1  x110
   n1  n11 22 1  x111
   n1  n12 24 1  x112
   n1  n13 21 1  x113
   n2  n10 23 1  x210
   n2  n11 19 1  x211
   n2  n12 28 1  x212
   n2  n13 22 1  x213
   n3  n10 27 1  x310
   n3  n11 23 1  x311
   n3  n12 21 1  x312
   n3  n13 25 1  x313
   n4  n14 21 1  x414
   n4  n15 27 1  x415
   n4  n16 25 1  x416
   n4  n17 21 1  x417
   n5  n14 21 1  x514
   n5  n15 23 1  x515
   n5  n16 23 1  x516
   n5  n17 23 1  x517
   n6  n14 19 1  x614
```

```
   n6  n15 28 1  x615
   n6  n16 26 1  x616
   n6  n17 26 1  x617
   n7  n18 28 1  x718
   n7  n19 24 1  x719
   n7  n20 23 1  x720
   n7  n21 22 1  x721
   n8  n18 24 1  x818
   n8  n19 23 1  x819
   n8  n20 23 1  x820
   n8  n21 19 1  x821
   n9  n18 26 1  x918
   n9  n19 22 1  x919
   n9  n20 22 1  x920
   n9  n21 19 1  x921
   n10 t   0  1  x10t
   n11 t   0  1  x11t
   n12 t   0  1  x12t
   n13 t   0  1  x13t
   n14 t   0  1  x14t
   n15 t   0  1  x15t
   n16 t   0  1  x16t
   n17 t   0  1  x17t
   n18 t   0  1  x18t
   n19 t   0  1  x19t
   n20 t   0  1  x20t
   n21 t   0  1  x21t
   t   s   0  .  xts
   t   n4  0  .  xt4
   t   n5  0  .  xt5
   t   n6  0  .  xt6
   t   n7  0  .  xt7
   t   n8  0  .  xt8
   t   n9  0  .  xt9
;

title3 'Side constraints';
data cond1;
   input
   x110 x111 x112 x113 x210 x211 x212 x213 x310 x311 x312 x313 x414 x415 x416
   x417 x514 x515 x516 x517 x614 x615 x616 x617 x718 x719 x720 x721 x818 x819
   x820 x821 x918 x919 x920 x921 xts xs1 xs2 xs3 xt4 xt5 xt6 xt7 xt8 xt9
   _type_ $ _rhs_;
   cards;

4 . . .  . 4 . .  . . 4 .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  -1  . . . . . . . . .  eq 0
4 . . .  . 4 . .  . . . 4  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  -1  . . . . . . . . .  eq 0
. 4 . .  . . 4 .  . . . 4  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  -1  . . . . . . . . .  le 0
. 4 . .  . . . 4  . . 4 .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  -1  . . . . . . . . .  le 0
. 4 . .  4 . . .  . . . 4  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  -1  . . . . . . . . .  le 0
. . 4 .  4 . . .  . . . 4  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  -1  . . . . . . . . .  le 0
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  .  -1 . . 1 . . . . .  eq 0
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  .  -1 . . . . . 1 . .  eq 0
```

```
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . -1 . . 1 . . . . eq 0
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . -1 . . . . . 1 . eq 0
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . -1 . . 1 . . . eq 0
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . -1 . . . . . 1 eq 0
-1 . . .  . . . .  . . . .  1 . . .  . . . .  . . . .  . . . . . . . . . . . . . . . . . . . . . . eq 0
-1 . . .  . . . .  . . . .  . . . .  . . . .  . . . .  1 . . . . . . . . . . . . . . . . . . . . . eq 0
. -1 . .  . . . .  . . . .  . 1 . .  . . . .  . . . .  . . . . . . . . . . . . . . . . . . . . . . eq 0
. -1 . .  . . . .  . . . .  . . . .  . . . .  . . . .  . 1 . . . . . . . . . . . . . . . . . . . . eq 0
. . -1 .  . . . .  . . . .  . . 1 .  . . . .  . . . .  . . . . . . . . . . . . . . . . . . . . . . eq 0
. . -1 .  . . . .  . . . .  . . . .  . . . .  . . . .  . . 1 . . . . . . . . . . . . . . . . . . . eq 0
. . . -1  . . . .  . . . .  . . . 1  . . . .  . . . .  . . . . . . . . . . . . . . . . . . . . . . eq 0
. . . -1  . . . .  . . . .  . . . .  . . . .  . . . .  . . . 1 . . . . . . . . . . . . . . . . . . eq 0
;

proc netflow
  nodedata=noded
  arcdata=arcd1
  condata=cond1
  conout=solution
  max
  sourcenode=s
  sinknode=t
  namectrl=1;

proc print data=solution;
sum _fcost_;
```

Q.2 Solution

OBS	_FROM_	_TO_	_COST_	_CAPAC_	_LO_	_NAME_	_SUPPLY_	_DEMAND_	_FLOW_	_FCOST_	_RCOST_	_ANUMB_	_TNUMB_	_STATUS_
1	s	n1	0	4	0	XS1	.	.	0.00000	0.000	.	2	1	KEY_ARC BASIC
2	n1	n10	20	1	0	X110	.	.	0.00000	0.000	.	5	2	NONKEY ARC BASIC
3	n2	n10	23	1	0	X210	.	.	0.00000	0.000	-4.0000	6	3	LOWERBD NONBASIC
4	n3	n10	27	1	0	X310	.	.	1.00000	27.000	.	7	4	KEY_ARC BASIC
5	n1	n11	22	1	0	X111	.	.	0.00000	0.000	-4.0000	8	2	LOWERBD NONBASIC
6	n2	n11	19	1	0	X211	.	.	0.33333	6.333	.	9	3	NONKEY ARC BASIC
7	n3	n11	23	1	0	X311	.	.	0.66667	15.333	.	10	4	KEY_ARC BASIC
8	n1	n12	24	1	0	X112	.	.	0.00000	0.000	.	11	2	NONKEY ARC BASIC
9	n2	n12	28	1	0	X212	.	.	0.33333	9.333	.	12	3	KEY_ARC BASIC
10	n3	n12	21	1	0	X312	.	.	0.66667	14.000	.	13	4	NONKEY ARC BASIC
11	n1	n13	21	1	0	X113	.	.	0.00000	0.000	.	14	2	NONKEY ARC BASIC
12	n2	n13	22	1	0	X213	.	.	0.33333	7.333	.	15	3	NONKEY ARC BASIC
13	n3	n13	25	1	0	X313	.	.	0.66667	16.667	.	16	4	KEY_ARC BASIC
14	n4	n14	21	1	0	X414	.	.	0.00000	0.000	.	18	9	KEY_ARC BASIC
15	n5	n14	21	1	0	X514	.	.	1.00000	21.000	1.0000	19	14	UPPERBD NONBASIC
16	n6	n14	19	1	0	X614	.	.	0.00000	0.000	-2.0000	20	15	LOWERBD NONBASIC
17	n4	n15	27	1	0	X415	.	.	0.00000	0.000	.	21	9	NONKEY ARC BASIC
18	n5	n15	23	1	0	X515	.	.	0.00000	0.000	-4.0000	22	14	LOWERBD NONBASIC
19	n6	n15	28	1	0	X615	.	.	1.00000	28.000	.	23	15	KEY_ARC BASIC
20	n4	n16	25	1	0	X416	.	.	0.00000	0.000	.	24	9	NONKEY ARC BASIC
21	n5	n16	23	1	0	X516	.	.	0.00000	0.000	-2.0000	25	14	LOWERBD NONBASIC
22	n6	n16	26	1	0	X616	.	.	1.00000	26.000	.	26	15	KEY_ARC BASIC
23	n4	n17	21	1	0	X417	.	.	0.00000	0.000	-3.0000	27	9	LOWERBD NONBASIC
24	n5	n17	23	1	0	X517	.	.	0.00000	0.000	-2.0000	28	14	LOWERBD NONBASIC
25	n6	n17	26	1	0	X617	.	.	1.00000	26.000	.	29	15	KEY_ARC BASIC
26	n7	n18	28	1	0	X718	.	.	0.00000	0.000	.	33	16	KEY_ARC BASIC
27	n8	n18	24	1	0	X818	.	.	0.00000	0.000	-2.0000	34	21	LOWERBD NONBASIC
28	n9	n18	26	1	0	X918	.	.	1.00000	26.000	1.0000	35	22	UPPERBD NONBASIC
29	n7	n19	24	1	0	X719	.	.	0.00000	0.000	.	36	16	KEY_ARC BASIC
30	n8	n19	23	1	0	X819	.	.	0.00000	0.000	.	37	21	NONKEY ARC BASIC
31	n9	n19	22	1	0	X919	.	.	1.00000	22.000	0.0000	38	22	UPPERBD NONBASIC
32	s	n2	0	4	0	XS2	.	.	1.00000	0.000	.	3	1	KEY_ARC BASIC
33	n7	n20	23	1	0	X720	.	.	0.00000	0.000	.	39	16	KEY_ARC BASIC
34	n8	n20	23	1	0	X820	.	.	1.00000	23.000	.	40	21	NONKEY ARC BASIC
35	n9	n20	22	1	0	X920	.	.	0.00000	0.000	.	41	22	NONKEY ARC BASIC
36	n7	n21	22	1	0	X721	.	.	0.00000	0.000	.	42	16	KEY_ARC BASIC
37	n8	n21	19	1	0	X821	.	.	0.00000	0.000	-1.0000	43	21	LOWERBD NONBASIC
38	n9	n21	19	1	0	X921	.	.	1.00000	19.000	.	44	22	NONKEY ARC BASIC
39	s	n3	0	4	0	XS3	.	.	3.00000	0.000	.	4	1	KEY_ARC BASIC
40	t	n4	0	99999999	0	XT4	.	.	0.00000	0.000	.	17	23	KEY_ARC BASIC
41	t	n5	0	99999999	0	XT5	.	.	1.00000	0.000	.	30	23	KEY_ARC BASIC
42	t	n6	0	99999999	0	XT6	.	.	3.00000	0.000	.	31	23	KEY_ARC BASIC
43	t	n7	0	99999999	0	XT7	.	.	0.00000	0.000	.	32	23	KEY_ARC BASIC
44	t	n8	0	99999999	0	XT8	.	.	1.00000	0.000	.	45	23	KEY_ARC BASIC
45	t	n9	0	99999999	0	XT9	.	.	3.00000	0.000	.	46	23	KEY_ARC BASIC
46	t	s	0	99999999	0	XTS	.	.	4.00000	0.000	.	1	23	KEY_ARC BASIC
47	n10	t	0	1	0	X10T	.	D	1.00000	0.000	5.0000	47	5	UPPERBD NONBASIC
48	n11	t	0	1	0	X11T	.	D	1.00000	0.000	1.0000	48	6	UPPERBD NONBASIC
49	n12	t	0	1	0	X12T	.	D	1.00000	0.000	2.0000	49	7	UPPERBD NONBASIC
50	n13	t	0	1	0	X13T	.	D	1.00000	0.000	.	50	8	NONKEY ARC BASIC
51	n14	t	0	1	0	X14T	.	D	1.00000	0.000	.	51	10	NONKEY ARC BASIC
52	n15	t	0	1	0	X15T	.	D	1.00000	0.000	7.0000	52	11	UPPERBD NONBASIC
53	n16	t	0	1	0	X16T	.	D	1.00000	0.000	5.0000	53	12	UPPERBD NONBASIC
54	n17	t	0	1	0	X17T	.	D	1.00000	0.000	5.0000	54	13	UPPERBD NONBASIC
55	n18	t	0	1	0	X18T	.	D	1.00000	0.000	68.0000	55	17	UPPERBD NONBASIC
56	n19	t	0	1	0	X19T	.	D	1.00000	0.000	65.0000	56	18	UPPERBD NONBASIC
57	n20	t	0	1	0	X20T	.	D	1.00000	0.000	65.0000	57	19	UPPERBD NONBASIC
58	n21	t	0	1	0	X21T	.	D	1.00000	0.000	62.0000	58	20	UPPERBD NONBASIC
										=======				
										287.000				

Appendix R. *MIP-83 Formulation And Solution (p = 2)*

```
MIP83 maxproj2 output maxproj2.dat

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..TITLE
           Maximal Coverage MIP83 (d=5, p=2)

..OBJECTIVE MAXIMIZE

*state 1
   20 [[x101]] + 22 [[x111]] + 24 [[x121]] + 21 [[x131]]
 + 23 [[x102]] + 19 [[x112]] + 28 [[x122]] + 22 [[x132]]
 + 27 [[x103]] + 23 [[x113]] + 21 [[x123]]   25 [[x133]]

*state 2
 + 21 [[x144]] + 27 [[x154]] + 25 [[x164]] + 21 [[x174]]
 + 21 [[x145]] + 23 [[x155]] + 23 [[x165]] + 23 [[x175]]
 + 19 [[x146]] + 28 [[x156]] + 26 [[x166]] + 26 [[x176]]

*state 3
 + 28 [[x187]] + 24 [[x197]] + 23 [[x207]] + 22 [[x217]]
 + 24 [[x188]] + 23 [[x198]] + 23 [[x208]] + 19 [[x218]]
 + 26 [[x189]] + 22 [[x199]] + 22 [[x209]] + 19 [[x219]]

*state 1 facilities
 + 0 [[y1]] + 0 [[y2]] + 0 [[y3]]
*state 2 facilities
 + 0 [[y4]] + 0 [[y5]] + 0 [[y6]]
*state 3 facilities
 + 0 [[y7]] + 0 [[y8]] + 0 [[y9]]


..CONSTRAINTS

*state 1:  a sat cannot be observed unless a facility is avail

 y1 - x101 >= 0
 y1 - x111 >= 0
 y1 - x121 >= 0
 y1 - x131 >= 0

 y2 - x102 >= 0
```

```
 y2 - x112 >= 0
 y2 - x122 >= 0
 y2 - x132 >= 0

 y3 - x103 >= 0
 y3 - x113 >= 0
 y3 - x123 >= 0
 y3 - x133 >= 0

*state 2:  a sat cannot be observed unless a facility is avail

 y4 - x144 >= 0
 y4 - x154 >= 0
 y4 - x164 >= 0
 y4 - x174 >= 0

 y5 - x145 >= 0
 y5 - x155 >= 0
 y5 - x165 >= 0
 y5 - x175 >= 0


 y6 - x146 >= 0
 y6 - x156 >= 0
 y6 - x166 >= 0
 y6 - x176 >= 0


*state 3:  a sat cannot be observed unless a facility is avail

 y7 - x187 >= 0
 y7 - x197 >= 0
 y7 - x207 >= 0
 y7 - x217 >= 0

 y8 - x188 >= 0
 y8 - x198 >= 0
 y8 - x208 >= 0
 y8 - x218 >= 0

 y9 - x189 >= 0
 y9 - x199 >= 0
 y9 - x209 >= 0
 y9 - x219 >= 0


*state 1:  min # of times satellite to be imaged (d=5)
 20 x101 + 23 x102 + 27 x103  >= 5
 22 x111 + 19 x112 + 23 x113  >= 5
 24 x121 + 28 x122 + 21 x123  >= 5
 21 x131 + 22 x132 + 25 x133  >= 5
```

```
*state 2:  min # of times satellite to be imaged (d=5)
 21 x144 + 21 x145 + 19 x146  >= 5
 27 x154 + 23 x155 + 28 x156  >= 5
 25 x164 + 23 x165 + 26 x166  >= 5
 21 x174 + 23 x175 + 26 x176  >= 5

*state 3:  min # of times satellite to be imaged (d=5)
 28 x187 + 24 x188 + 26 x189  >= 5
 24 x197 + 23 x198 + 22 x199  >= 5
 23 x207 + 23 x208 + 22 x209  >= 5
 22 x217 + 19 x218 + 19 x219  >= 5


*If facility is in place in one state, must be in other state

 y1 - y4 = 0
 y1 - y7 = 0

 y2 - y5 = 0
 y2 - y8 = 0

 y3 - y6 = 0
 y3 - y9 = 0


*Restriction on the number of facilities (p=2)

 y1 + y2 + y3 = 2

Statistics-
  MIP83 Version 5.00a
  Machine memory:  550K bytes.
  Pagable memory:  252K bytes.
  Objective Function is MAXIMIZED.
  MIP Strategy:      1
  Variables:        45
    Integer:        45
  Constraints:      55
     0 LE,    7 EQ,  48 GE.
  Non-zero LP elements:     123
  Disk Space:     0K bytes.
  Page Space:    25K bytes.
  Capacity: 12.7% used.
  Estimated Time: 00:00:17

Iter  100
Solution Time:  00:00:02
*May have* A L T E R N A T E   S O L U T I O N

INTEGER SOLUTION
```

File: Maxproj2 11/16/92 10:09:54 Page 1-1
SOLUTION (Maximized): 562.0000 Maximal Coverage MIP83 (d=5, p=

Variable	Activity	Cost	Variable	Activity	Cost
x101	1.0000	20.0000	x111	1.0000	22.0000
x121	1.0000	24.0000	x131	1.0000	21.0000
x102	0.0000	23.0000	x112	0.0000	19.0000
x122	0.0000	28.0000	x132	0.0000	22.0000
x103	1.0000	27.0000	x113	1.0000	23.0000
x123	1.0000	21.0000	x133	1.0000	25.0000
x144	1.0000	21.0000	x154	1.0000	27.0000
x164	1.0000	25.0000	x174	1.0000	21.0000
x145	0.0000	21.0000	x155	0.0000	23.0000
x165	0.0000	23.0000	x175	0.0000	23.0000

File: Maxproj2 11/16/92 10:09:54 Page 1-2
SOLUTION (Maximized): 562.0000 Maximal Coverage MIP83 (d=5, p=

Variable	Activity	Cost	Variable	Activity	Cost
x146	1.0000	19.0000	x156	1.0000	28.0000
x166	1.0000	26.0000	x176	1.0000	26.0000
x187	1.0000	28.0000	x197	1.0000	24.0000
x207	1.0000	23.0000	x217	1.0000	22.0000
x188	0.0000	24.0000	x198	0.0000	23.0000
x208	0.0000	23.0000	x218	0.0000	19.0000
x189	1.0000	26.0000	x199	1.0000	22.0000
x209	1.0000	22.0000	x219	1.0000	19.0000
y1	1.0000	0.0000	y2	0.0000	0.0000
y3	1.0000	0.0000	y4	1.0000	0.0000

File: Maxproj2 11/16/92 10:09:54 Page 1-3
SOLUTION (Maximized): 562.0000 Maximal Coverage MIP83 (d=5, p=

Variable	Activity	Cost	Variable	Activity	Cost
y5	0.0000	0.0000	y6	1.0000	0.0000
y7	1.0000	0.0000	y8	0.0000	0.0000
y9	1.0000	0.0000			

File: Maxproj2 11/16/92 10:09:54 Page 1-4
CONSTRAINTS: Maximal Coverage MIP83 (d=5, p=2)

Constraint	Activity	RHS	Constraint	Activity	RHS
Row 1	0.0000 >	0.0000	Row 2	0.0000 >	0.0000
Row 3	0.0000 >	0.0000	Row 4	0.0000 >	0.0000
Row 5	0.0000 >	0.0000	Row 6	0.0000 >	0.0000
Row 7	0.0000 >	0.0000	Row 8	0.0000 >	0.0000
Row 9	0.0000 >	0.0000	Row 10	0.0000 >	0.0000
Row 11	0.0000 >	0.0000	Row 12	0.0000 >	0.0000
Row 13	0.0000 >	0.0000	Row 14	0.0000 >	0.0000
Row 15	0.0000 >	0.0000	Row 16	0.0000 >	0.0000
Row 17	0.0000 >	0.0000	Row 18	0.0000 >	0.0000
Row 19	0.0000 >	0.0000	Row 20	0.0000 >	0.0000

File: Maxproj2 11/16/92 10:09:54 Page 1-5

CONSTRAINTS: Maximal Coverage MIP83 (d=5, p=2)

Constraint	Activity		RHS	Constraint	Activity		RHS
Row 21	0.0000	>	0.0000	Row 22	0.0000	>	0.0000
Row 23	0.0000	>	0.0000	Row 24	0.0000	>	0.0000
Row 25	0.0000	>	0.0000	Row 26	0.0000	>	0.0000
Row 27	0.0000	>	0.0000	Row 28	0.0000	>	0.0000
Row 29	0.0000	>	0.0000	Row 30	0.0000	>	0.0000
Row 31	0.0000	>	0.0000	Row 32	0.0000	>	0.0000
Row 33	0.0000	>	0.0000	Row 34	0.0000	>	0.0000
Row 35	0.0000	>	0.0000	Row 36	0.0000	>	0.0000
I Row 37	47.0000	>	5.0000	I Row 38	45.0000	>	5.0000
I Row 39	45.0000	>	5.0000	I Row 40	46.0000	>	5.0000

File: Maxproj2 11/16/92 10:09:54 Page 1-6

CONSTRAINTS: Maximal Coverage MIP83 (d=5, p=2)

Constraint	Activity		RHS	Constraint	Activity		RHS
I Row 41	40.0000	>	5.0000	I Row 42	55.0000	>	5.0000
I Row 43	51.0000	>	5.0000	I Row 44	47.0000	>	5.0000
I Row 45	54.0000	>	5.0000	I Row 46	46.0000	>	5.0000
I Row 47	45.0000	>	5.0000	I Row 48	41.0000	>	5.0000
Row 49	0.0000	=	0.0000	Row 50	0.0000	=	0.0000
Row 51	0.0000	=	0.0000	Row 52	0.0000	=	0.0000
Row 53	0.0000	=	0.0000	Row 54	0.0000	=	0.0000
Row 55	2.0000	=	2.0000				

Total Error: 0.000000

Appendix S. *Network With Side Constraints ($p = 2$)*

S.1 Formulation

```
options linesize=120;
options pagesize=66;
title 'Facility Location - run 13';
title3 'Nodes for Facility Location';
   data noded;
      input _node_ $ _sd_;
      cards;
   s 0
   t 0
;

title3 'Arcs for Facility Location';
   data arcd1;
      input _from_ $ _to_ $ _cost_ _capac_ _name_ $;
      cards;
   s   n1  0  12  xs1
   s   n2  0  12  xs2
   s   n3  0  12  xs3
   n1  n10 20 1  x110
   n1  n11 22 1  x111
   n1  n12 24 1  x112
   n1  n13 21 1  x113
   n1  n4  0  8  x14
   n2  n10 23 1  x210
   n2  n11 19 1  x211
   n2  n12 28 1  x212
   n2  n13 22 1  x213
   n2  n5  0  8  x25
   n3  n10 27 1  x310
   n3  n11 23 1  x311
   n3  n12 21 1  x312
   n3  n13 25 1  x313
   n3  n6  0  8  x36
   n4  n14 21 1  x414
   n4  n15 27 1  x415
   n4  n16 25 1  x416
   n4  n17 21 1  x417
   n4  n7  0  4  x47
   n5  n14 21 1  x514
   n5  n15 23 1  x515
   n5  n16 23 1  x516
   n5  n17 23 1  x517
   n5  n8  0  4  x58
   n6  n14 19 1  x614
   n6  n15 28 1  x615
```

```
   n6  n16 26 1  x616
   n6  n17 26 1  x617
   n6  n9  0  4  x69
   n7  n18 28 1  x718
   n7  n19 24 1  x719
   n7  n20 23 1  x720
   n7  n21 22 1  x721
   n8  n18 24 1  x818
   n8  n19 23 1  x819
   n8  n20 23 1  x820
   n8  n21 19 1  x821
   n9  n18 26 1  x918
   n9  n19 22 1  x919
   n9  n20 22 1  x920
   n9  n21 19 1  x921
   n10 t   0  2  x10t
   n11 t   0  2  x11t
   n12 t   0  2  x12t
   n13 t   0  2  x13t
   n14 t   0  2  x14t
   n15 t   0  2  x15t
   n16 t   0  2  x16t
   n17 t   0  2  x17t
   n18 t   0  2  x18t
   n19 t   0  2  x19t
   n20 t   0  2  x20t
   n21 t   0  2  x21t
   t   s   0  .  xts
;

title3 'Side constraints';
data cond1;
   input xs1 xs2 xs3 x110 x111 x112 x113 x14 x210 x211 x212 x213 x25
   x310 x311 x312 x313 x36 x414 x415 x416 x417 x47 x514 x515 x516 x517 x58
   x614 x615 x616 x617 x69 x718 x719 x720 x721 x818 x819 x820 x821
   x918 x919 x920 x921 _type_ $ _rhs_;
   cards;

-1 . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
-1 . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
-1 . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
-1 . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
-8 . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. -1 . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. -1 . . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. -1 . . . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. -1 . . . . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. -8 . . . . . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . -1 . . . . . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . -1 . . . . . . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . -1 . . . . . . . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . -1 . . . . . . . . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . -8 . . . . . . . . . . . . . . 12 . . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . . . . . . -1 . . . . . . . . . . 8 . . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . . . . . . -1 . . . . . . . . . . . 8 . . . . . . . . . . . . . . . . . . . . . . . . . = 0
```

```
. . . . . . . -1 . . . . . . . . . . . . 8 . . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . . . . . . -1 . . . . . . . . . . . . . 8 . . . . . . . . . . . . . . . . . . . . . . . . = 0
. . . . . . . -1 . . . . . . . . . . . . . . 2 . . . . . . . . . . . . . . . . . . . . . . . = 0
. . . . . . . . . . . . -1 . . . . . . . . . . 8 . . . . . . . . . . . . . . . . . . . . . . = 0
. . . . . . . . . . . . -1 . . . . . . . . . . . 8 . . . . . . . . . . . . . . . . . . . . . = 0
. . . . . . . . . . . . -1 . . . . . . . . . . . . 8 . . . . . . . . . . . . . . . . . . . . = 0
. . . . . . . . . . . . -1 . . . . . . . . . . . . . 8 . . . . . . . . . . . . . . . . . . . = 0
. . . . . . . . . . . . -1 . . . . . . . . . . . . . . 2 . . . . . . . . . . . . . . . . . . = 0
. . . . . . . . . . . . . . . . . -1 . . . . . . . . . . 8 . . . . . . . . . . . . . . . . . = 0
. . . . . . . . . . . . . . . . . -1 . . . . . . . . . . . 8 . . . . . . . . . . . . . . . . = 0
. . . . . . . . . . . . . . . . . -1 . . . . . . . . . . . . 8 . . . . . . . . . . . . . . . = 0
. . . . . . . . . . . . . . . . . -1 . . . . . . . . . . . . . 8 . . . . . . . . . . . . . . = 0
. . . . . . . . . . . . . . . . . -1 . . . . . . . . . . . . . . 2 . . . . . . . . . . . . . = 0
;

proc netflow
  nodedata=noded
  arcdata=arcd1
  condata=cond1
  conout=solution
  max
  sourcenode=s
  sinknode=t
  namectrl=1;

proc print data=solution;
sum _fcost_;
```

S.2 Solution

OBS	_FROM_	_TO_	_COST_	_CAPAC_	_LO_	_NAME_	_SUPPLY_	_DEMAND_	_FLOW_	_FCOST_	_RCOST_	_ANUMB_	_TNUMB_	_STATUS_
1	s	n1	0	12	0	XS1	S	.	12.0000	0.000	.	2	1	KEY_ARC BASIC
2	n1	n10	20	1	0	X110	.	.	1.0000	20.000	.	5	2	KEY_ARC BASIC
3	n2	n10	23	1	0	X210	.	.	0.0000	0.000	.	6	3	NONKEY ARC BASIC
4	n3	n10	27	1	0	X310	.	.	1.0000	27.000	.	7	4	NONKEY ARC BASIC
5	n1	n11	22	1	0	X111	.	.	1.0000	22.000	.	8	2	NONKEY ARC BASIC
6	n2	n11	19	1	0	X211	.	.	0.0000	0.000	.	9	3	KEY_ARC BASIC
7	n3	n11	23	1	0	X311	.	.	1.0000	23.000	13.000	10	4	UPPERBD NONBASIC
8	n1	n12	24	1	0	X112	.	.	1.0000	24.000	.	11	2	NONKEY ARC BASIC
9	n2	n12	28	1	0	X212	.	.	0.0000	0.000	.	12	3	NONKEY ARC BASIC
10	n3	n12	21	1	0	X312	.	.	1.0000	21.000	.	13	4	KEY_ARC BASIC
11	n1	n13	21	1	0	X113	.	.	1.0000	21.000	.	14	2	KEY_ARC BASIC
12	n2	n13	22	1	0	X213	.	.	0.0000	0.000	.	15	3	NONKEY ARC BASIC
13	n3	n13	25	1	0	X313	.	.	1.0000	25.000	.	16	4	NONKEY ARC BASIC
14	n4	n14	21	1	0	X414	.	.	1.0000	21.000	.	20	9	NONKEY ARC BASIC
15	n5	n14	21	1	0	X514	.	.	0.0000	0.000	.	21	10	NONKEY ARC BASIC
16	n6	n14	19	1	0	X614	.	.	1.0000	19.000	.	22	11	KEY_ARC BASIC
17	n4	n15	27	1	0	X415	.	.	1.0000	27.000	.	23	9	NONKEY ARC BASIC
18	n5	n15	23	1	0	X515	.	.	0.0000	0.000	.	24	10	KEY_ARC BASIC
19	n6	n15	28	1	0	X615	.	.	1.0000	28.000	.	25	11	NONKEY ARC BASIC
20	n4	n16	25	1	0	X416	.	.	1.0000	25.000	.	26	9	NONKEY ARC BASIC
21	n5	n16	23	1	0	X516	.	.	0.0000	0.000	.	27	10	KEY_ARC BASIC
22	n6	n16	26	1	0	X616	.	.	1.0000	26.000	.	28	11	NONKEY ARC BASIC
23	n4	n17	21	1	0	X417	.	.	1.0000	21.000	.	29	9	NONKEY ARC BASIC
24	n5	n17	23	1	0	X517	.	.	0.0000	0.000	.	30	10	NONKEY ARC BASIC
25	n6	n17	26	1	0	X617	.	.	1.0000	26.000	.	31	11	KEY_ARC BASIC
26	n7	n18	28	1	0	X718	.	.	1.0000	28.000	.	35	16	NONKEY ARC BASIC
27	n8	n18	24	1	0	X818	.	.	0.0000	0.000	.	36	17	NONKEY ARC BASIC
28	n9	n18	26	1	0	X918	.	.	1.0000	26.000	.	37	18	KEY_ARC BASIC
29	n7	n19	24	1	0	X719	.	.	1.0000	24.000	.	38	16	NONKEY ARC BASIC
30	n8	n19	23	1	0	X819	.	.	0.0000	0.000	.	39	17	NONKEY ARC BASIC
31	n9	n19	22	1	0	X919	.	.	1.0000	22.000	.	40	18	KEY_ARC BASIC
32	s	n2	0	12	0	XS2	S	.	0.0000	0.000	.	3	1	KEY_ARC BASIC
33	n7	n20	23	1	0	X720	.	.	1.0000	23.000	.	41	16	NONKEY ARC BASIC
34	n8	n20	23	1	0	X820	.	.	0.0000	0.000	.	42	17	NONKEY ARC BASIC
35	n9	n20	22	1	0	X920	.	.	1.0000	22.000	.	43	18	KEY_ARC BASIC
36	n7	n21	22	1	0	X721	.	.	1.0000	22.000	7.000	44	16	UPPERBD NONBASIC
37	n8	n21	19	1	0	X821	.	.	0.0000	0.000	.	45	17	NONKEY ARC BASIC
38	n9	n21	19	1	0	X921	.	.	1.0000	19.000	.	46	18	KEY_ARC BASIC
39	s	n3	0	12	0	XS3	S	.	12.0000	0.000	.	4	1	KEY_ARC BASIC
40	n1	n4	0	8	0	X14	.	.	8.0000	0.000	.	17	2	KEY_ARC BASIC
41	n2	n5	0	8	0	X25	.	.	0.0000	0.000	.	18	3	KEY_ARC BASIC
42	n3	n6	0	8	0	X36	.	.	8.0000	0.000	.	19	4	KEY_ARC BASIC
43	n4	n7	0	4	0	X47	.	.	4.0000	0.000	.	32	9	KEY_ARC BASIC
44	n5	n8	0	4	0	X58	.	.	0.0000	0.000	.	33	10	KEY_ARC BASIC
45	n6	n9	0	4	0	X69	.	.	4.0000	0.000	.	34	11	KEY_ARC BASIC
46	t	s	0	99999999	0	XTS	.	.	24.0000	0.000	.	1	23	KEY_ARC BASIC
47	n10	t	0	2	0	X10T	.	D	2.0000	0.000	.	47	5	NONKEY ARC BASIC
48	n11	t	0	2	0	X11T	.	D	2.0000	0.000	.	48	6	NONKEY ARC BASIC
49	n12	t	0	2	0	X12T	.	D	2.0000	0.000	.	49	7	NONKEY ARC BASIC
50	n13	t	0	2	0	X13T	.	D	2.0000	0.000	.	50	8	NONKEY ARC BASIC
51	n14	t	0	2	0	X14T	.	D	2.0000	0.000	.	51	12	NONKEY ARC BASIC
52	n15	t	0	2	0	X15T	.	D	2.0000	0.000	.	52	13	NONKEY ARC BASIC
53	n16	t	0	2	0	X16T	.	D	2.0000	0.000	.	53	14	NONKEY ARC BASIC
54	n17	t	0	2	0	X17T	.	D	2.0000	0.000	.	54	15	NONKEY ARC BASIC
55	n18	t	0	2	0	X18T	.	D	2.0000	0.000	265.000	55	19	UPPERBD NONBASIC
56	n19	t	0	2	0	X19T	.	D	2.0000	0.000	3.000	56	20	UPPERBD NONBASIC
57	n20	t	0	2	0	X20T	.	D	2.0000	0.000	3.000	57	21	UPPERBD NONBASIC
58	n21	t	0	2	0	X21T	.	D	2.0000	0.000	.	58	22	NONKEY ARC BASIC
										=======				
										562.000				

Appendix T. *NWSC Multi-Commodity Flow Formulation ($p = 2$)*

T.1 Formulation

```
options linesize=120;
options pagesize=66;
title 'Facility Location - run 14';
title3 'Nodes for Facility Location';
   data noded;
      input _node_ $ _sd_;
      cards;
   s  0
   n4 0
   n5 0
   n6 0
   n7 0
   n8 0
   n9 0
   t  0
;

title3 'Arcs for Facility Location';
   data arcd1;
      input _from_ $ _to_ $ _cost_ _capac_ _name_ $;
      cards;
   s   n1   0 4  xs1
   s   n2   0 4  xs2
   s   n3   0 4  xs3
   n1  n10 20 1  x110
   n1  n11 22 1  x111
   n1  n12 24 1  x112
   n1  n13 21 1  x113
   n2  n10 23 1  x210
   n2  n11 19 1  x211
   n2  n12 28 1  x212
   n2  n13 22 1  x213
   n3  n10 27 1  x310
   n3  n11 23 1  x311
   n3  n12 21 1  x312
   n3  n13 25 1  x313
   n4  n14 21 1  x414
   n4  n15 27 1  x415
   n4  n16 25 1  x416
   n4  n17 21 1  x417
   n5  n14 21 1  x514
   n5  n15 23 1  x515
   n5  n16 23 1  x516
   n5  n17 23 1  x517
   n6  n14 19 1  x614
```

```
   n6  n15 28 1  x615
   n6  n16 26 1  x616
   n6  n17 26 1  x617
   n7  n18 28 1  x718
   n7  n19 24 1  x719
   n7  n20 23 1  x720
   n7  n21 22 1  x721
   n8  n18 24 1  x818
   n8  n19 23 1  x819
   n8  n20 23 1  x820
   n8  n21 19 1  x821
   n9  n18 26 1  x918
   n9  n19 22 1  x919
   n9  n20 22 1  x920
   n9  n21 19 1  x921
   n10 t   0  2  x10t
   n11 t   0  2  x11t
   n12 t   0  2  x12t
   n13 t   0  2  x13t
   n14 t   0  2  x14t
   n15 t   0  2  x15t
   n16 t   0  2  x16t
   n17 t   0  2  x17t
   n18 t   0  2  x18t
   n19 t   0  2  x19t
   n20 t   0  2  x20t
   n21 t   0  2  x21t
   t   s   0  .  xts
   t   n4  0  .  xt4
   t   n5  0  .  xt5
   t   n6  0  .  xt6
   t   n7  0  .  xt7
   t   n8  0  .  xt8
   t   n9  0  .  xt9
;

title3 'Side constraints';
data cond1;
   input
   x110 x111 x112 x113 x210 x211 x212 x213 x310 x311 x312 x313 x414 x415 x416
   x417 x514 x515 x516 x517 x614 x615 x616 x617 x718 x719 x720 x721 x818 x819
   x820 x821 x918 x919 x920 x921 xts xs1 xs2 xs3 xt4 xt5 xt6 xt7 xt8 xt9
   _type_ $ _rhs_;
   cards;

4 . . .  . 4 . .  . . 4 .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  -1  . . .  . . . . . .  le 0
4 . . .  . 4 . .  . . . 4  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  -1  . . .  . . . . . .  le 0
. 4 . .  . . 4 .  . . . 4  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  -1  . . .  . . . . . .  le 0
. 4 . .  . . . 4  . . 4 .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  -1  . . .  . . . . . .  le 0
. 4 . .  4 . . .  . . . 4  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  -1  . . .  . . . . . .  le 0
. . 4 .  4 . . .  . . . 4  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  -1  . . .  . . . . . .  le 0
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .   .  -1 . .  1 . . . . .  eq 0
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . .   .  -1 . .  . . . 1 . .  eq 0
```

```
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . . . . .  . . . -1 . . 1 . . . . eq 0
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . . . . .  . . . -1 . . . . . 1 . eq 0
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . . . . .  . . . . -1 . . 1 . . . eq 0
. . . .  . . . .  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . . . . .  . . . . -1 . . . . . 1 eq 0
-1 . . .  . . . .  . . . .  1 . . .  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . . . . . . . . eq 0
-1 . . .  . . . .  . . . .  . . . .  . . . .  . . . .  1 . . .  . . . .  . . . . . . . . . . . . . . . . eq 0
. -1 . .  . . . .  . . . .  . 1 . .  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . . . . . . . . eq 0
. -1 . .  . . . .  . . . .  . . . .  . . . .  . . . .  . 1 . .  . . . .  . . . . . . . . . . . . . . . . eq 0
. . -1 .  . . . .  . . . .  . . 1 .  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . . . . . . . . eq 0
. . -1 .  . . . .  . . . .  . . . .  . . . .  . . . .  . . 1 .  . . . .  . . . . . . . . . . . . . . . . eq 0
. . . -1  . . . .  . . . .  . . . 1  . . . .  . . . .  . . . .  . . . .  . . . . . . . . . . . . . . . . eq 0
. . . -1  . . . .  . . . .  . . . .  . . . .  . . . .  . . . 1  . . . .  . . . . . . . . . . . . . . . . eq 0
. . . .  -1 . . .  . . . .  . . . .  1 . . .  . . . .  . . . .  . . . .  . . . . . . . . . . . . . . . . eq 0
. . . .  -1 . . .  . . . .  . . . .  . . . .  . . . .  . . . .  1 . . .  . . . . . . . . . . . . . . . . eq 0
. . . .  . -1 . .  . . . .  . . . .  . 1 . .  . . . .  . . . .  . . . .  . . . . . . . . . . . . . . . . eq 0
. . . .  . -1 . .  . . . .  . . . .  . . . .  . . . .  . . . .  . 1 . .  . . . . . . . . . . . . . . . . eq 0
. . . .  . . -1 .  . . . .  . . . .  . . 1 .  . . . .  . . . .  . . . .  . . . . . . . . . . . . . . . . eq 0
. . . .  . . -1 .  . . . .  . . . .  . . . .  . . . .  . . . .  . . 1 .  . . . . . . . . . . . . . . . . eq 0
. . . .  . . . -1  . . . .  . . . .  . . . 1  . . . .  . . . .  . . . .  . . . . . . . . . . . . . . . . eq 0
. . . .  . . . -1  . . . .  . . . .  . . . .  . . . .  . . . .  . . . 1  . . . . . . . . . . . . . . . . eq 0
;

proc netflow
  nodedata=noded
  arcdata=arcd1
  condata=cond1
  conout=solution
  max
  sourcenode=s
  sinknode=t
  namectrl=1;

proc print data=solution;
sum _fcost_;
```

T.2 Solution

OBS	_FROM_	_TO_	_COST_	_CAPAC_	_LO_	_NAME_	_SUPPLY_	_DEMAND_	_FLOW_	_FCOST_	_RCOST_	_ANUMB_	_TNUMB_	_STATUS_
1	s	n1	0	4	0	XS1	.	.	4	0	.	2	1	KEY_ARC BASIC
2	n1	n10	20	1	0	X110	.	.	1	20	.	5	2	KEY_ARC BASIC
3	n2	n10	23	1	0	X210	.	.	0	0	.	6	3	NONKEY ARC BASIC
4	n3	n10	27	1	0	X310	.	.	1	27	4.0000	7	4	UPPERBD NONBASIC
5	n1	n11	22	1	0	X111	.	.	1	22	.	8	2	NONKEY ARC BASIC
6	n2	n11	19	1	0	X211	.	.	0	0	.	9	3	KEY_ARC BASIC
7	n3	n11	23	1	0	X311	.	.	1	23	4.0000	10	4	UPPERBD NONBASIC
8	n1	n12	24	1	0	X112	.	.	1	24	4.0000	11	2	UPPERBD NONBASIC
9	n2	n12	28	1	0	X212	.	.	0	0	.	12	3	NONKEY ARC BASIC
10	n3	n12	21	1	0	X312	.	.	1	21	.	13	4	KEY_ARC BASIC
11	n1	n13	21	1	0	X113	.	.	1	21	.	14	2	KEY_ARC BASIC
12	n2	n13	22	1	0	X213	.	.	0	0	.	15	3	NONKEY ARC BASIC
13	n3	n13	25	1	0	X313	.	.	1	25	.	16	4	NONKEY ARC BASIC
14	n4	n14	21	1	0	X414	.	.	1	21	.	18	9	NONKEY ARC BASIC
15	n5	n14	21	1	0	X514	.	.	0	0	0.0000	19	14	LOWERBD NONBASIC
16	n6	n14	19	1	0	X614	.	.	1	19	.	20	15	KEY_ARC BASIC
17	n4	n15	27	1	0	X415	.	.	1	27	.	21	9	NONKEY ARC BASIC
18	n5	n15	23	1	0	X515	.	.	0	0	.	22	14	KEY_ARC BASIC
19	n6	n15	28	1	0	X615	.	.	1	28	2.0000	23	15	UPPERBD NONBASIC
20	n4	n16	25	1	0	X416	.	.	1	25	.	24	9	NONKEY ARC BASIC
21	n5	n16	23	1	0	X516	.	.	0	0	.	25	14	KEY_ARC BASIC
22	n6	n16	26	1	0	X616	.	.	1	26	.	26	15	NONKEY ARC BASIC
23	n4	n17	21	1	0	X417	.	.	1	21	.	27	9	KEY_ARC BASIC
24	n5	n17	23	1	0	X517	.	.	0	0	0.0000	28	14	LOWERBD NONBASIC
25	n6	n17	26	1	0	X617	.	.	1	26	.	29	15	NONKEY ARC BASIC
26	n7	n18	28	1	0	X718	.	.	1	28	.	33	16	NONKEY ARC BASIC
27	n8	n18	24	1	0	X818	.	.	0	0	.	34	21	KEY_ARC BASIC
28	n9	n18	26	1	0	X918	.	.	1	26	.	35	22	NONKEY ARC BASIC
29	n7	n19	24	1	0	X719	.	.	1	24	.	36	16	NONKEY ARC BASIC
30	n8	n19	23	1	0	X819	.	.	0	0	-3.0000	37	21	LOWERBD NONBASIC
31	n9	n19	22	1	0	X919	.	.	1	22	.	38	22	KEY_ARC BASIC
32	s	n2	0	4	0	XS2	.	.	0	0	.	3	1	KEY_ARC BASIC
33	n7	n20	23	1	0	X720	.	.	1	23	.	39	16	NONKEY ARC BASIC
34	n8	n20	23	1	0	X820	.	.	0	0	.	40	21	NONKEY ARC BASIC
35	n9	n20	22	1	0	X920	.	.	1	22	.	41	22	KEY_ARC BASIC
36	n7	n21	22	1	0	X721	.	.	1	22	.	42	16	NONKEY ARC BASIC
37	n8	n21	19	1	0	X821	.	.	0	0	.	43	21	NONKEY ARC BASIC
38	n9	n21	19	1	0	X921	.	.	1	19	.	44	22	KEY_ARC BASIC
39	s	n3	0	4	0	XS3	.	.	4	0	.	4	1	KEY_ARC BASIC
40	t	n4	0	99999999	0	XT4	.	.	4	0	.	17	23	KEY_ARC BASIC
41	t	n5	0	99999999	0	XT5	.	.	0	0	.	30	23	KEY_ARC BASIC
42	t	n6	0	99999999	0	XT6	.	.	4	0	.	31	23	KEY_ARC BASIC
43	t	n7	0	99999999	0	XT7	.	.	4	0	.	32	23	KEY_ARC BASIC
44	t	n8	0	99999999	0	XT8	.	.	0	0	.	45	23	KEY_ARC BASIC
45	t	n9	0	99999999	0	XT9	.	.	4	0	.	46	23	KEY_ARC BASIC
46	t	s	0	99999999	0	XTS	.	.	8	0	.	1	23	KEY_ARC BASIC
47	n10	t	0	2	0	X10T	.	D	2	0	4.0000	47	5	UPPERBD NONBASIC
48	n11	t	0	2	0	X11T	.	D	2	0	.	48	6	NONKEY ARC BASIC
49	n12	t	0	2	0	X12T	.	D	2	0	1.0000	49	7	UPPERBD NONBASIC
50	n13	t	0	2	0	X13T	.	D	2	0	.	50	8	NONKEY ARC BASIC
51	n14	t	0	2	0	X14T	.	D	2	0	.	51	10	NONKEY ARC BASIC
52	n15	t	0	2	0	X15T	.	D	2	0	7.0000	52	11	UPPERBD NONBASIC
53	n16	t	0	2	0	X16T	.	D	2	0	7.0000	53	12	UPPERBD NONBASIC
54	n17	t	0	2	0	X17T	.	D	2	0	7.0000	54	13	UPPERBD NONBASIC
55	n18	t	0	2	0	X18T	.	D	2	0	65.7500	55	17	UPPERBD NONBASIC
56	n19	t	0	2	0	X19T	.	D	2	0	61.7500	56	18	UPPERBD NONBASIC
57	n20	t	0	2	0	X20T	.	D	2	0	61.7500	57	19	UPPERBD NONBASIC
58	n21	t	0	2	0	X21T	.	D	2	0	58.7500	58	20	UPPERBD NONBASIC
										=======				
										562				

Appendix U. *Target Satellites and Selected Orbital Elements*

Satellite	JD of Epoch	ndot	i	Omega	e	omega	M	Mean motion
USA_36	197.91837137	0.00007202	47.6914	82.0767	0.0006038	270.6002	89.4230	15.30488629
USA_51	198.08591563	0.00003400	43.0917	158.4372	0.0016607	188.8480	171.2446	15.10915290
USA_52	197.94609706	0.00007885	43.0999	127.3948	0.0021313	188.0041	172.0547	15.37361834
KRISTALL	197.83302827	0.00022163	51.6116	181.0813	0.0009828	150.3263	209.8281	15.62965269
ROSAT	197.88269321	0.00001427	52.9893	278.5644	0.0016534	72.3616	287.9167	14.97805315
USA_50	191.64282447	0.00000001	54.5508	255.0660	0.0027829	44.9864	315.3289	2.00872988
USA_54	196.82871687	-0.00000032	55.1008	14.7818	0.0036435	102.9248	257.5125	2.00550609
USA_63	218.99722221	0.00000016	54.7146	194.1753	0.0137525	116.3366	181.4646	1.99250853
COSMOS_2027	197.60108149	0.00008487	65.8353	256.4158	0.0011393	165.3891	194.7581	15.34317472
COSMOS_2079	197.25939867	-0.00000015	64.8901	37.9878	0.0021686	210.6750	149.2556	2.13102429
COSMOS_2084	197.73310099	0.00001275	62.8050	91.6109	0.0125122	7.7699	352.5256	14.66800001
COSMOS_2087	206.81007288	0.00000085	62.8980	166.2331	0.7346085	318.1243	4.5758	2.04190646
MOLNIYA3-35	197.60435990	-0.00000163	63.6146	41.5478	0.7439871	288.3776	8.9683	2.00579957
MOLNIYA3-38	197.61610821	-0.00000276	62.8106	222.5276	0.7409990	280.1641	11.0192	2.00629826
COSMOS_2053	197.45259090	0.00005067	73.5319	30.1588	0.0012445	130.7206	229.5063	15.16816703
COSMOS_2064	197.75221122	0.00000009	73.9827	115.8203	0.0016865	121.6719	238.5972	12.47022722
COSMOS_2082	197.60464049	0.00000407	71.0014	248.9610	0.0006932	316.1147	43.9455	14.12202222
COSMOS_2088	211.30945199	-0.00000007	73.6024	315.1795	0.0026045	274.7578	85.0478	12.40541957
EXOS_D	197.49004303	0.00017349	75.1016	224.4887	0.4172240	203.0971	130.9587	7.12367692
COSMOS_1975	220.76572722	0.00000356	82.5347	272.1928	0.0022698	263.8456	96.0078	14.77357130
COSMOS_1994	198.07614051	0.00000004	82.6188	64.2228	0.0012384	284.3905	75.5843	12.64036285
GRANAT	195.00000000	-0.00000774	65.4200	347.9100	0.9095563	304.6110	340.6870	0.24400759
MAGION_2	197.75571572	0.00000983	82.5943	209.7055	0.1256316	271.3998	74.4042	12.44078582
M_1	197.46759000	0.00001179	89.8880	194.3530	0.0115325	45.9621	315.1018	14.60855102
NADEZHDA	197.60044991	0.00000085	82.9589	263.3143	0.0036784	318.4962	41.3401	13.73599910
OSCAR_25	196.27623727	0.00000194	89.9246	136.7689	0.0099175	12.7405	347.6205	13.40556745
COBE	193.09621556	0.00002713	99.0190	203.0552	0.0008422	301.8581	58.1758	14.02561379
COSMOS_1484	198.11006872	0.00002525	97.6731	247.3242	0.0041609	332.0470	27.8506	14.88821640
COSMOS_1689	198.01536703	0.00004681	97.7535	265.6947	0.0049657	18.0635	342.2337	14.96154722
COSMOS_1939	197.98291795	0.00001694	97.8625	257.8830	0.0025465	244.9853	114.8807	14.83492321

DEBUT	195.61058361	0.00000052	99.0367	236.9380	0.0540983	346.5085	12.2023	12.83158694
FENGYUN_1	198.08145838	0.00000249	99.1964	179.1309	0.0075686	324.3139	35.2982	14.01357692
IRAS	191.52552230	-0.00000080	99.0225	27.9613	0.0011826	324.5176	35.5228	13.98794439
IRS_1A	198.02791305	-0.00000084	98.9643	265.1622	0.0012623	164.9896	195.1630	13.96279164
LANDSAT_4	196.90103716	0.00000128	98.1638	258.8646	0.0004643	51.4083	308.7526	14.57138609
LANDSAT_5	196.92892046	0.00000400	98.2032	256.5710	0.0001826	113.6647	246.4746	14.57120276
METEOR_1-30	198.11290548	0.00009749	97.6730	298.0707	0.0027071	302.0099	57.8505	15.19565463
METEOR_PRIRODA	196.96612028	0.00001423	97.7623	176.7612	0.0033609	137.6758	222.7063	14.83242315
MOS_1	198.05442718	0.00000229	99.1080	270.2241	0.0001102	87.5815	272.5490	13.94871513
MOS_1B	198.01052009	0.00000085	99.1896	268.1044	0.0000784	57.3307	302.7941	13.94832098
NOAA_11	197.51102764	0.00000170	98.9820	145.8534	0.0011656	196.5791	163.4991	14.11647557
NOAA_8	195.53786854	0.00000451	98.5231	205.2102	0.0017634	92.6379	267.6814	14.23837726
NOAA_9	198.22643387	0.00000261	99.1690	198.7542	0.0014262	286.2590	73.7008	14.12618650
SME	196.63693036	0.00029056	97.6335	245.8541	0.0000657	245.5455	114.5775	15.52837284
SPOT_1	197.66656711	0.00000293	98.7329	271.7257	0.0002045	99.9436	260.1903	14.20023935
UOSAT	196.62757134	0.00001107	97.9462	248.2520	0.0013012	152.5037	207.6821	14.65494071
USA_26	196.92322052	0.00000377	98.8186	27.1385	0.0013703	303.3182	56.6689	14.14080993
USA_29	198.25799871	-0.00000422	98.6409	76.6667	0.0006552	175.7377	184.3856	14.21487952
USA_55	197.61537977	0.00000002	94.1399	230.7213	0.0127346	223.5919	135.5190	14.95672063
VIKING	168.05847800	0.00000100	98.8000	52.1847	0.4707161	229.0139	79.6586	5.50351493

Appendix V. *Partial Listing: NWSC Using Implied Gains ($p = 1$)*

V.1 Formulation

```
options linesize=120;
options pagesize=66;
title 'Network with Side Constraints';
title3 'Nodes for Facility Location';
   data noded;
      input _node_ $ _sd_;
      cards;
   s  0
   t  0
;

title3 'Arcs for Facility Location';
   data arcd1;
      input _from_ $ _to_ $ _cost_ _capac_ _name_ $;
      cards;
   s    a1     0 48  xsa1
   s    b1     0 48  xsb1
   s    c1     0 48  xsc1
   s    d1     0 48  xsd1
   s    e1     0 48  xse1
   s    f1     0 48  xsf1
   s    g1     0 48  xsg1
   s    h1     0 48  xsh1
   s    i1     0 48  xsi1
   s    j1     0 48  xsj1
   s    k1     0 48  xsk1
   s    l1     0 48  xsl1

   a1   n01    0  1  xa101
   a1   n02   60  1  xa102
   a1   n03   60  1  xa103
   a1   n04   32  1  xa104
   a1   n05  264  1  xa105
```

⋮

```
   13   n35   55  1  x1335
   13   n36   60  1  x1336
   13   n37  244  1  x1337
   13   n38  173  1  x1338
   13   n39  250  1  x1339
   13   n40  298  1  x1340
```

13	n41	298	1	x1341
13	n42	228	1	x1342
13	n43	300	1	x1343
13	n44	297	1	x1344
13	n45	297	1	x1345
13	n46	299	1	x1346
13	n47	230	1	x1347
13	n48	165	1	x1348

n01	t	0	1	x01t
n02	t	0	1	x02t
n03	t	0	1	x03t
n04	t	0	1	x04t
n05	t	0	1	x05t
n06	t	0	1	x06t
n07	t	0	1	x07t
n08	t	0	1	x08t
n09	t	0	1	x09t
n10	t	0	1	x10t
n11	t	0	1	x11t
n12	t	0	1	x12t
n13	t	0	1	x13t
n14	t	0	1	x14t
n15	t	0	1	x15t
n16	t	0	1	x16t
n17	t	0	1	x17t
n18	t	0	1	x18t
n19	t	0	1	x19t
n20	t	0	1	x20t
n21	t	0	1	x21t
n22	t	0	1	x22t
n23	t	0	1	x23t
n24	t	0	1	x24t
n25	t	0	1	x25t
n26	t	0	1	x26t
n27	t	0	1	x27t
n28	t	0	1	x28t
n29	t	0	1	x29t
n30	t	0	1	x30t
n31	t	0	1	x31t
n32	t	0	1	x32t
n33	t	0	1	x33t
n34	t	0	1	x34t
n35	t	0	1	x35t
n36	t	0	1	x36t
n37	t	0	1	x37t
n38	t	0	1	x38t
n39	t	0	1	x39t
n40	t	0	1	x40t
n41	t	0	1	x41t
n42	t	0	1	x42t

```
   n43  t      0  1  x43t
   n44  t      0  1  x44t
   n45  t      0  1  x45t
   n46  t      0  1  x46t
   n47  t      0  1  x47t
   n48  t      0  1  x48t
   t    s      0  .  xts1
;

title3 'Side constraints';
data cond1;

   input xsa1 xsb1 xsc1 xsd1 xse1 xsf1 xsg1 xsh1 xsi1 xsj1 xsk1 xsl1
         xa101 xa102 xa103 xa104 xa105 xa106 xa107 xa108 xa109 xa110 xa111 xa112 xa113 xa114 xa115 xa116 xa1a2
         xb101 xb102 xb103 xb104 xb105 xb106 xb107 xb108 xb109 xb110 xb111 xb112 xb113 xb114 xb115 xb116 xb1b2
         xc101 xc102 xc103 xc104 xc105 xc106 xc107 xc108 xc109 xc110 xc111 xc112 xc113 xc114 xc115 xc116 xc1c2
         xd101 xd102 xd103 xd104 xd105 xd106 xd107 xd108 xd109 xd110 xd111 xd112 xd113 xd114 xd115 xd116 xd1d2
         xe101 xe102 xe103 xe104 xe105 xe106 xe107 xe108 xe109 xe110 xe111 xe112 xe113 xe114 xe115 xe116 xe1e2
         xf101 xf102 xf103 xf104 xf105 xf106 xf107 xf108 xf109 xf110 xf111 xf112 xf113 xf114 xf115 xf116 xf1f2
         xg101 xg102 xg103 xg104 xg105 xg106 xg107 xg108 xg109 xg110 xg111 xg112 xg113 xg114 xg115 xg116 xg1g2
         xh101 xh102 xh103 xh104 xh105 xh106 xh107 xh108 xh109 xh110 xh111 xh112 xh113 xh114 xh115 xh116 xh1h2
         xi101 xi102 xi103 xi104 xi105 xi106 xi107 xi108 xi109 xi110 xi111 xi112 xi113 xi114 xi115 xi116 xi1i2
         xj101 xj102 xj103 xj104 xj105 xj106 xj107 xj108 xj109 xj110 xj111 xj112 xj113 xj114 xj115 xj116 xj1j2
         xk101 xk102 xk103 xk104 xk105 xk106 xk107 xk108 xk109 xk110 xk111 xk112 xk113 xk114 xk115 xk116 xk1k2
         xl101 xl102 xl103 xl104 xl105 xl106 xl107 xl108 xl109 xl110 xl111 xl112 xl113 xl114 xl115 xl116 xl1l2
         xa217 xa218 xa219 xa220 xa221 xa222 xa223 xa224 xa225 xa226 xa227 xa228 xa229 xa230 xa231 xa232 xa2a3
         xb217 xb218 xb219 xb220 xb221 xb222 xb223 xb224 xb225 xb226 xb227 xb228 xb229 xb230 xb231 xb232 xb2b3
         xc217 xc218 xc219 xc220 xc221 xc222 xc223 xc224 xc225 xc226 xc227 xc228 xc229 xc230 xc231 xc232 xc2c3
         xd217 xd218 xd219 xd220 xd221 xd222 xd223 xd224 xd225 xd226 xd227 xd228 xd229 xd230 xd231 xd232 xd2d3
         xe217 xe218 xe219 xe220 xe221 xe222 xe223 xe224 xe225 xe226 xe227 xe228 xe229 xe230 xe231 xe232 xe2e3
         xf217 xf218 xf219 xf220 xf221 xf222 xf223 xf224 xf225 xf226 xf227 xf228 xf229 xf230 xf231 xf232 xf2f3
         xg217 xg218 xg219 xg220 xg221 xg222 xg223 xg224 xg225 xg226 xg227 xg228 xg229 xg230 xg231 xg232 xg2g3
         xh217 xh218 xh219 xh220 xh221 xh222 xh223 xh224 xh225 xh226 xh227 xh228 xh229 xh230 xh231 xh232 xh2h3
         xi217 xi218 xi219 xi220 xi221 xi222 xi223 xi224 xi225 xi226 xi227 xi228 xi229 xi230 xi231 xi232 xi2i3
         xj217 xj218 xj219 xj220 xj221 xj222 xj223 xj224 xj225 xj226 xj227 xj228 xj229 xj230 xj231 xj232 xj2j3
         xk217 xk218 xk219 xk220 xk221 xk222 xk223 xk224 xk225 xk226 xk227 xk228 xk229 xk230 xk231 xk232 xk2k3
         xl217 xl218 xl219 xl220 xl221 xl222 xl223 xl224 xl225 xl226 xl227 xl228 xl229 xl230 xl231 xl232 xl2l3
         xa333 xa334 xa335 xa336 xa337 xa338 xa339 xa340 xa341 xa342 xa343 xa344 xa345 xa346 xa347 xa348
         xb333 xb334 xb335 xb336 xb337 xb338 xb339 xb340 xb341 xb342 xb343 xb344 xb345 xb346 xb347 xb348
         xc333 xc334 xc335 xc336 xc337 xc338 xc339 xc340 xc341 xc342 xc343 xc344 xc345 xc346 xc347 xc348
         xd333 xd334 xd335 xd336 xd337 xd338 xd339 xd340 xd341 xd342 xd343 xd344 xd345 xd346 xd347 xd348
         xe333 xe334 xe335 xe336 xe337 xe338 xe339 xe340 xe341 xe342 xe343 xe344 xe345 xe346 xe347 xe348
         xf333 xf334 xf335 xf336 xf337 xf338 xf339 xf340 xf341 xf342 xf343 xf344 xf345 xf346 xf347 xf348
         xg333 xg334 xg335 xg336 xg337 xg338 xg339 xg340 xg341 xg342 xg343 xg344 xg345 xg346 xg347 xg348
         xh333 xh334 xh335 xh336 xh337 xh338 xh339 xh340 xh341 xh342 xh343 xh344 xh345 xh346 xh347 xh348
         xi333 xi334 xi335 xi336 xi337 xi338 xi339 xi340 xi341 xi342 xi343 xi344 xi345 xi346 xi347 xi348
         xj333 xj334 xj335 xj336 xj337 xj338 xj339 xj340 xj341 xj342 xj343 xj344 xj345 xj346 xj347 xj348
         xk333 xk334 xk335 xk336 xk337 xk338 xk339 xk340 xk341 xk342 xk343 xk344 xk345 xk346 xk347 xk348
         xl333 xl334 xl335 xl336 xl337 xl338 xl339 xl340 xl341 xl342 xl343 xl344 xl345 xl346 xl347 xl348
  _type_ $ _rhs_;
   cards;
-1 . . . . . . . . . . . .
48 . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . .
. . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . .
. . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . .
. . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . .
   . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . .
   . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . .
   . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . .
   . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . .
      . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . .
      . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . .
```

```
    . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .
    . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . . = 0

-1 . . . . . . . . . . . .
. 48 . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . . .
. . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . . .
. . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . . .
. . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . . .
  . . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . . .
  . . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . . .
  . . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . . .
  . . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . . .
    . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .
    . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .
    . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .
    . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . . = 0

    ⋮
⋮
⋮

proc netflow
  nodedata=noded
  arcdata=arcd1
  condata=cond1
  conout=solution
  max
  sourcenode=s
  sinknode=t
  namectrl=1;

proc print data=solution;
sum _fcost_;
```

V.2 Solution

Solution was not obtained due to computer round off error which caused the matrix to become singular.

Appendix W. *Case Study – NWSC Multi-Commodity Flow Formulation*

W.1 Formulation – Partial Listing For $p = 3$

```
options linesize=120;
options pagesize=66;
title 'Case Study -- NWSC Multi-Commodity Flow';
title3 'Nodes for Facility Location';
   data noded;
      input _node_ $ _sd_;
      cards;
   s1 0
   s2 0
   s3 0
   t  0
;

title3 'Arcs for Facility Location';
   data arcd1;
      input _from_ $ _to_ $ _cost_ _capac_ _name_ $;
      cards;
   s1   a1      0 16  xs1a1
   s1   b1      0 16  xs1b1
   s1   c1      0 16  xs1c1
   s1   d1      0 16  xs1d1
   s1   e1      0 16  xs1e1
   s1   f1      0 16  xs1f1
   s1   g1      0 16  xs1g1
   s1   h1      0 16  xs1h1
   s1   i1      0 16  xs1i1
   s1   j1      0 16  xs1j1
   s1   k1      0 16  xs1k1
   s1   l1      0 16  xs1l1
   s2   a2      0 16  xs2a2
   s2   b2      0 16  xs2b2
   s2   c2      0 16  xs2c2
   s2   d2      0 16  xs2d2
   s2   e2      0 16  xs2e2
   s2   f2      0 16  xs2f2
   s2   g2      0 16  xs2g2
   s2   h2      0 16  xs2h2
   s2   i2      0 16  xs2i2
   s2   j2      0 16  xs2j2
   s2   k2      0 16  xs2k2
   s2   l2      0 16  xs2l2
   s3   a3      0 16  xs3a3
   s3   b3      0 16  xs3b3
   s3   c3      0 16  xs3c3
   s3   d3      0 16  xs3d3
   s3   e3      0 16  xs3e3
   s3   f3      0 16  xs3f3
```

```
s3    g3      0 16   xs3g3
s3    h3      0 16   xs3h3
s3    i3      0 16   xs3i3
s3    j3      0 16   xs3j3
s3    k3      0 16   xs3k3
s3    l3      0 16   xs3l3

a1    n01     0  1   xa101
a1    n02    60  1   xa102
a1    n03    60  1   xa103
a1    n04    32  1   xa104
a1    n05   264  1   xa105
```

⋮

```
l3    n34    64  1   xl334
l3    n35    55  1   xl335
l3    n36    60  1   xl336
l3    n37   244  1   xl337
l3    n38   173  1   xl338
l3    n39   250  1   xl339
l3    n40   298  1   xl340
l3    n41   298  1   xl341
l3    n42   228  1   xl342
l3    n43   300  1   xl343
l3    n44   297  1   xl344
l3    n45   297  1   xl345
l3    n46   299  1   xl346
l3    n47   230  1   xl347
l3    n48   165  1   xl348

n01   t       0  3   x01t
n02   t       0  3   x02t
n03   t       0  3   x03t
n04   t       0  3   x04t
n05   t       0  3   x05t
n06   t       0  3   x06t
n07   t       0  3   x07t
n08   t       0  3   x08t
n09   t       0  3   x09t
n10   t       0  3   x10t
n11   t       0  3   x11t
n12   t       0  3   x12t
n13   t       0  3   x13t
n14   t       0  3   x14t
n15   t       0  3   x15t
n16   t       0  3   x16t
n17   t       0  3   x17t
n18   t       0  3   x18t
```

```
    n19  t    0  3  x19t
    n20  t    0  3  x20t
    n21  t    0  3  x21t
    n22  t    0  3  x22t
    n23  t    0  3  x23t
    n24  t    0  3  x24t
    n25  t    0  3  x25t
    n26  t    0  3  x26t
    n27  t    0  3  x27t
    n28  t    0  3  x28t
    n29  t    0  3  x29t
    n30  t    0  3  x30t
    n31  t    0  3  x31t
    n32  t    0  3  x32t
    n33  t    0  3  x33t
    n34  t    0  3  x34t
    n35  t    0  3  x35t
    n36  t    0  3  x36t
    n37  t    0  3  x37t
    n38  t    0  3  x38t
    n39  t    0  3  x39t
    n40  t    0  3  x40t
    n41  t    0  3  x41t
    n42  t    0  3  x42t
    n43  t    0  3  x43t
    n44  t    0  3  x44t
    n45  t    0  3  x45t
    n46  t    0  3  x46t
    n47  t    0  3  x47t
    n48  t    0  3  x48t
    t    s1   0  .  xts1
    t    s2   0  .  xts2
    t    s3   0  .  xts3
;

title3 'Side constraints';
data cond1;
   input

      xa101 xa102 xa103 xa104 xa105 xa106 xa107 xa108 xa109 xa110 xa111 xa112 xa113 xa114 xa115 xa116
      xb101 xb102 xb103 xb104 xb105 xb106 xb107 xb108 xb109 xb110 xb111 xb112 xb113 xb114 xb115 xb116
      xc101 xc102 xc103 xc104 xc105 xc106 xc107 xc108 xc109 xc110 xc111 xc112 xc113 xc114 xc115 xc116
      xd101 xd102 xd103 xd104 xd105 xd106 xd107 xd108 xd109 xd110 xd111 xd112 xd113 xd114 xd115 xd116
      xe101 xe102 xe103 xe104 xe105 xe106 xe107 xe108 xe109 xe110 xe111 xe112 xe113 xe114 xe115 xe116
      xf101 xf102 xf103 xf104 xf105 xf106 xf107 xf108 xf109 xf110 xf111 xf112 xf113 xf114 xf115 xf116
      xg101 xg102 xg103 xg104 xg105 xg106 xg107 xg108 xg109 xg110 xg111 xg112 xg113 xg114 xg115 xg116
      xh101 xh102 xh103 xh104 xh105 xh106 xh107 xh108 xh109 xh110 xh111 xh112 xh113 xh114 xh115 xh116
      xi101 xi102 xi103 xi104 xi105 xi106 xi107 xi108 xi109 xi110 xi111 xi112 xi113 xi114 xi115 xi116
      xj101 xj102 xj103 xj104 xj105 xj106 xj107 xj108 xj109 xj110 xj111 xj112 xj113 xj114 xj115 xj116
      xk101 xk102 xk103 xk104 xk105 xk106 xk107 xk108 xk109 xk110 xk111 xk112 xk113 xk114 xk115 xk116
      xl101 xl102 xl103 xl104 xl105 xl106 xl107 xl108 xl109 xl110 xl111 xl112 xl113 xl114 xl115 xl116
      xa217 xa218 xa219 xa220 xa221 xa222 xa223 xa224 xa225 xa226 xa227 xa228 xa229 xa230 xa231 xa232
      xb217 xb218 xb219 xb220 xb221 xb222 xb223 xb224 xb225 xb226 xb227 xb228 xb229 xb230 xb231 xb232
      xc217 xc218 xc219 xc220 xc221 xc222 xc223 xc224 xc225 xc226 xc227 xc228 xc229 xc230 xc231 xc232
      xd217 xd218 xd219 xd220 xd221 xd222 xd223 xd224 xd225 xd226 xd227 xd228 xd229 xd230 xd231 xd232
```

```
xe217 xe218 xe219 xe220 xe221 xe222 xe223 xe224 xe225 xe226 xe227 xe228 xe229 xe230 xe231 xe232
xf217 xf218 xf219 xf220 xf221 xf222 xf223 xf224 xf225 xf226 xf227 xf228 xf229 xf230 xf231 xf232
xg217 xg218 xg219 xg220 xg221 xg222 xg223 xg224 xg225 xg226 xg227 xg228 xg229 xg230 xg231 xg232
xh217 xh218 xh219 xh220 xh221 xh222 xh223 xh224 xh225 xh226 xh227 xh228 xh229 xh230 xh231 xh232
xi217 xi218 xi219 xi220 xi221 xi222 xi223 xi224 xi225 xi226 xi227 xi228 xi229 xi230 xi231 xi232
xj217 xj218 xj219 xj220 xj221 xj222 xj223 xj224 xj225 xj226 xj227 xj228 xj229 xj230 xj231 xj232
xk217 xk218 xk219 xk220 xk221 xk222 xk223 xk224 xk225 xk226 xk227 xk228 xk229 xk230 xk231 xk232
xl217 xl218 xl219 xl220 xl221 xl222 xl223 xl224 xl225 xl226 xl227 xl228 xl229 xl230 xl231 xl232
xa333 xa334 xa335 xa336 xa337 xa338 xa339 xa340 xa341 xa342 xa343 xa344 xa345 xa346 xa347 xa348
xb333 xb334 xb335 xb336 xb337 xb338 xb339 xb340 xb341 xb342 xb343 xb344 xb345 xb346 xb347 xb348
xc333 xc334 xc335 xc336 xc337 xc338 xc339 xc340 xc341 xc342 xc343 xc344 xc345 xc346 xc347 xc348
xd333 xd334 xd335 xd336 xd337 xd338 xd339 xd340 xd341 xd342 xd343 xd344 xd345 xd346 xd347 xd348
xe333 xe334 xe335 xe336 xe337 xe338 xe339 xe340 xe341 xe342 xe343 xe344 xe345 xe346 xe347 xe348
xf333 xf334 xf335 xf336 xf337 xf338 xf339 xf340 xf341 xf342 xf343 xf344 xf345 xf346 xf347 xf348
xg333 xg334 xg335 xg336 xg337 xg338 xg339 xg340 xg341 xg342 xg343 xg344 xg345 xg346 xg347 xg348
xh333 xh334 xh335 xh336 xh337 xh338 xh339 xh340 xh341 xh342 xh343 xh344 xh345 xh346 xh347 xh348
xi333 xi334 xi335 xi336 xi337 xi338 xi339 xi340 xi341 xi342 xi343 xi344 xi345 xi346 xi347 xi348
xj333 xj334 xj335 xj336 xj337 xj338 xj339 xj340 xj341 xj342 xj343 xj344 xj345 xj346 xj347 xj348
xk333 xk334 xk335 xk336 xk337 xk338 xk339 xk340 xk341 xk342 xk343 xk344 xk345 xk346 xk347 xk348
xl333 xl334 xl335 xl336 xl337 xl338 xl339 xl340 xl341 xl342 xl343 xl344 xl345 xl346 xl347 xl348
xts1 xts2 xts3
xs1a1 xs1b1 xs1c1 xs1d1 xs1e1 xs1f1 xs1g1 xs1h1 xs1i1 xs1j1 xs1k1 xs1l1
xs1a2 xs2b2 xs2c2 xs2d2 xs2e2 xs2f2 xs2g2 xs2h2 xs2i2 xs2j2 xs2k2 xs2l2
xs3a3 xs3b3 xs3c3 xs3d3 xs3e3 xs3f3 xs3g3 xs3h3 xs3i3 xs3j3 xs3k3 xs3l3  _type_ $ _rhs_;
cards;
```

Arc Restricting Constraints

```
16 . . . . . . . . . . . . . . .    . 16 . . . . . . . . . . . . . .    . . 16 . . . . . . . . . . . . .
. . . 16 . . . . . . . . . . . .    . . . . 16 . . . . . . . . . . .    . . . . . 16 . . . . . . . . . .
. . . . . . 16 . . . . . . . . .    . . . . . . . 16 . . . . . . . .    . . . . . . . . 16 . . . . . . .
. . . . . . . . . 16 . . . . . .    . . . . . . . . . . 16 . . . . .    . . . . . . . . . . . 16 . . . .
  . . . . . . . . . . . . . . . .    . . . . . . . . . . . . . . . .    . . . . . . . . . . . . . . . .
  . . . . . . . . . . . . . . . .    . . . . . . . . . . . . . . . .    . . . . . . . . . . . . . . . .
  . . . . . . . . . . . . . . . .    . . . . . . . . . . . . . . . .    . . . . . . . . . . . . . . . .
  . . . . . . . . . . . . . . . .    . . . . . . . . . . . . . . . .    . . . . . . . . . . . . . . . .
    . . . . . . . . . . . . . . . .    . . . . . . . . . . . . . . . .    . . . . . . . . . . . . . . . .
    . . . . . . . . . . . . . . . .    . . . . . . . . . . . . . . . .    . . . . . . . . . . . . . . . .
    . . . . . . . . . . . . . . . .    . . . . . . . . . . . . . . . .    . . . . . . . . . . . . . . . .
    . . . . . . . . . . . . . . . .    . . . . . . . . . . . . . . . .    . . . . . . . . . . . . . . . .
      -1 . .
      . . . . . . . . . . . .   . . . . . . . . . . . .   . . . . . . . . . . . .  le 0

16 . . . . . . . . . . . . . . .    . . 16 . . . . . . . . . . . . .    . . . 16 . . . . . . . . . . . .
. . . . 16 . . . . . . . . . . .    . . . . . 16 . . . . . . . . . .    . . . . . . 16 . . . . . . . . .
. . . . . . . 16 . . . . . . . .    . . . . . . . . 16 . . . . . . .    . . . . . . . . . 16 . . . . . .
. . . . . . . . . . 16 . . . . .    . . . . . . . . . . . 16 . . . .    . . . . . . . . . . . . 16 . . .
  . . . . . . . . . . . . . . . .    . . . . . . . . . . . . . . . .    . . . . . . . . . . . . . . . .
  . . . . . . . . . . . . . . . .    . . . . . . . . . . . . . . . .    . . . . . . . . . . . . . . . .
  . . . . . . . . . . . . . . . .    . . . . . . . . . . . . . . . .    . . . . . . . . . . . . . . . .
  . . . . . . . . . . . . . . . .    . . . . . . . . . . . . . . . .    . . . . . . . . . . . . . . . .
    . . . . . . . . . . . . . . . .    . . . . . . . . . . . . . . . .    . . . . . . . . . . . . . . . .
    . . . . . . . . . . . . . . . .    . . . . . . . . . . . . . . . .    . . . . . . . . . . . . . . . .
    . . . . . . . . . . . . . . . .    . . . . . . . . . . . . . . . .    . . . . . . . . . . . . . . . .
    . . . . . . . . . . . . . . . .    . . . . . . . . . . . . . . . .    . . . . . . . . . . . . . . . .
      -1 . .
      . . . . . . . . . . . .   . . . . . . . . . . . .   . . . . . . . . . . . .  le 0
```

⋮

Equal Distribution of Flow Constraints

```
16 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
-1 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . eq 0
. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 16 . . . . . . . . . . . . . . . . .
. . -1 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . eq 0
```

⋮

If State i, then State $i + 1, 2$, etc.

```
-1 . . . . . . . . . . . . 1 . . . . . . . . . . . . . . . . . . . . . . eq 0
```

```
 . . .
-1 . . . . . . . . . . . .   . . . . . . . . . . . . . .   1 . . . . . . . . . . . .   eq 0
```

⋮

Flow along like arcs in different states

```
-1 . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .
. . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .
. . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .
. . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .
  1 . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .
  . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .
  . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .
  . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .
    . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .
    . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .
    . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .
    . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .
      . . .
      . . . . . . . . . . . . . .   . . . . . . . . . . . . . .   . . . . . . . . . . . . . .   eq 0

-1 . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .
. . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .
. . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .
. . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .
  . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .
  . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .
  . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .
  . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .
    1 . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .
    . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .
    . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .
    . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .   . . . . . . . . . . . . . . . . . .
      . . .
      . . . . . . . . . . . . . .   . . . . . . . . . . . . . .   . . . . . . . . . . . . . .   eq 0
```

```
proc netflow
  nodedata=noded
  arcdata=arcd1
  condata=cond1
  conout=solution
  max
  sourcenode=s
  sinknode=t
  namectrl=1;

proc print data=solution;
sum _fcost_;
```

W.2 Solution for $p = 1$

OBS	_FROM_	_TO_	_COST_	_CAPAC_	_LO_	_NAME_	_SUPPLY_	_DEMAND_	_FLOW_	_FCOST_	_RCOST_	_ANUMB_	_TNUMB_	_STATUS_
1	s1	a1	0	16	0	XS1A1	.	.	0	0	.	2	1	KEY_ARC BASIC
2	s2	a2	0	16	0	XS2A2	.	.	0	0	.	15	14	KEY_ARC BASIC
3	s3	a3	0	16	0	XS3A3	.	.	0	0	.	28	27	KEY_ARC BASIC
4	s1	b1	0	16	0	XS1B1	.	.	0	0	.	3	1	KEY_ARC BASIC
5	s2	b2	0	16	0	XS2B2	.	.	0	0	.	16	14	KEY_ARC BASIC
6	s3	b3	0	16	0	XS3B3	.	.	0	0	.	29	27	KEY_ARC BASIC
7	s1	c1	0	16	0	XS1C1	.	.	16	0	.	4	1	KEY_ARC BASIC
8	s2	c2	0	16	0	XS2C2	.	.	16	0	.	17	14	KEY_ARC BASIC
9	s3	c3	0	16	0	XS3C3	.	.	16	0	.	30	27	KEY_ARC BASIC
10	s1	d1	0	16	0	XS1D1	.	.	0	0	.	5	1	KEY_ARC BASIC
11	s2	d2	0	16	0	XS2D2	.	.	0	0	.	18	14	KEY_ARC BASIC
12	s3	d3	0	16	0	XS3D3	.	.	0	0	.	31	27	KEY_ARC BASIC
13	s1	e1	0	16	0	XS1E1	.	.	0	0	.	6	1	KEY_ARC BASIC
14	s2	e2	0	16	0	XS2E2	.	.	0	0	.	19	14	KEY_ARC BASIC
15	s3	e3	0	16	0	XS3E3	.	.	0	0	.	32	27	KEY_ARC BASIC
16	s1	f1	0	16	0	XS1F1	.	.	0	0	.	7	1	KEY_ARC BASIC
17	s2	f2	0	16	0	XS2F2	.	.	0	0	.	20	14	KEY_ARC BASIC
18	s3	f3	0	16	0	XS3F3	.	.	0	0	.	33	27	KEY_ARC BASIC
19	s1	g1	0	16	0	XS1G1	.	.	0	0	.	8	1	KEY_ARC BASIC
20	s2	g2	0	16	0	XS2G2	.	.	0	0	.	21	14	KEY_ARC BASIC
21	s3	g3	0	16	0	XS3G3	.	.	0	0	.	34	27	KEY_ARC BASIC
22	s1	h1	0	16	0	XS1H1	.	.	0	0	.	9	1	KEY_ARC BASIC
23	s2	h2	0	16	0	XS2H2	.	.	0	0	.	22	14	KEY_ARC BASIC
24	s3	h3	0	16	0	XS3H3	.	.	0	0	.	35	27	KEY_ARC BASIC
25	s1	i1	0	16	0	XS1I1	.	.	0	0	.	10	1	KEY_ARC BASIC
26	s2	i2	0	16	0	XS2I2	.	.	0	0	.	23	14	KEY_ARC BASIC
27	s3	i3	0	16	0	XS3I3	.	.	0	0	.	36	27	KEY_ARC BASIC
28	s1	j1	0	16	0	XS1J1	.	.	0	0	.	11	1	KEY_ARC BASIC
29	s2	j2	0	16	0	XS2J2	.	.	0	0	.	24	14	KEY_ARC BASIC
30	s3	j3	0	16	0	XS3J3	.	.	0	0	.	37	27	NONKEY ARC BASIC
31	s1	k1	0	16	0	XS1K1	.	.	0	0	.	12	1	KEY_ARC BASIC
32	s2	k2	0	16	0	XS2K2	.	.	0	0	.	25	14	KEY_ARC BASIC
33	s3	k3	0	16	0	XS3K3	.	.	0	0	.	38	27	NONKEY ARC BASIC
34	s1	l1	0	16	0	XS1L1	.	.	0	0	.	13	1	KEY_ARC BASIC
35	s2	l2	0	16	0	XS2L2	.	.	0	0	.	26	14	KEY_ARC BASIC
36	s3	l3	0	16	0	XS3L3	.	.	0	0	.	39	27	NONKEY ARC BASIC
37	a1	n01	0	1	0	XA101	.	.	0	0	.	40	2	NONKEY ARC BASIC
38	b1	n01	160	1	0	XB101	.	.	0	0	-24	41	3	LOWERBD NONBASIC
39	c1	n01	108	1	0	XC101	.	.	1	108	.	42	4	NONKEY ARC BASIC
40	d1	n01	134	1	0	XD101	.	.	0	0	-90	43	5	LOWERBD NONBASIC
41	e1	n01	157	1	0	XE101	.	.	0	0	.	44	6	NONKEY ARC BASIC
42	f1	n01	148	1	0	XF101	.	.	0	0	-73	45	7	LOWERBD NONBASIC
43	g1	n01	157	1	0	XG101	.	.	0	0	-40	46	8	LOWERBD NONBASIC
44	h1	n01	155	1	0	XH101	.	.	0	0	-52	47	9	LOWERBD NONBASIC
45	i1	n01	167	1	0	XI101	.	.	0	0	.	48	10	KEY_ARC BASIC
46	j1	n01	165	1	0	XJ101	.	.	0	0	.	49	11	NONKEY ARC BASIC
47	k1	n01	90	1	0	XK101	.	.	0	0	-209	50	12	LOWERBD NONBASIC
48	l1	n01	70	1	0	XL101	.	.	0	0	-259	51	13	LOWERBD NONBASIC
49	a1	n02	60	1	0	XA102	.	.	0	0	.	52	2	KEY_ARC BASIC
50	b1	n02	60	1	0	XB102	.	.	0	0	-4	53	3	LOWERBD NONBASIC
51	c1	n02	60	1	0	XC102	.	.	1	60	.	54	4	NONKEY ARC BASIC
52	d1	n02	60	1	0	XD102	.	.	0	0	-8	55	5	LOWERBD NONBASIC
53	e1	n02	60	1	0	XE102	.	.	0	0	.	56	6	NONKEY ARC BASIC
54	f1	n02	60	1	0	XF102	.	.	0	0	-16	57	7	LOWERBD NONBASIC
55	g1	n02	60	1	0	XG102	.	.	0	0	-8	58	8	LOWERBD NONBASIC
56	h1	n02	60	1	0	XH102	.	.	0	0	.	59	9	NONKEY ARC BASIC
57	i1	n02	60	1	0	XI102	.	.	0	0	.	60	10	NONKEY ARC BASIC
58	j1	n02	60	1	0	XJ102	.	.	0	0	-1	61	11	LOWERBD NONBASIC
59	k1	n02	60	1	0	XK102	.	.	0	0	-131	62	12	LOWERBD NONBASIC
60	l1	n02	60	1	0	XL102	.	.	0	0	-165	63	13	LOWERBD NONBASIC

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61	a1	n03	60	1	0	XA103	.	.	0	0	.	64	2	KEY_ARC BASIC
62	b1	n03	49	1	0	XB103	.	.	0	0	.	65	3	NONKEY ARC BASIC
63	c1	n03	60	1	0	XC103	.	.	1	60	919	66	4	UPPERBD NONBASIC
64	d1	n03	60	1	0	XD103	.	.	0	0	.	67	5	NONKEY ARC BASIC
65	e1	n03	42	1	0	XE103	.	.	0	0	-18	68	6	LOWERBD NONBASIC
66	f1	n03	60	1	0	XF103	.	.	0	0	-6	69	7	LOWERBD NONBASIC
67	g1	n03	59	1	0	XG103	.	.	0	0	.	70	8	NONKEY ARC BASIC
68	h1	n03	60	1	0	XH103	.	.	0	0	.	71	9	NONKEY ARC BASIC
69	i1	n03	51	1	0	XI103	.	.	0	0	.	72	10	NONKEY ARC BASIC
70	j1	n03	45	1	0	XJ103	.	.	0	0	-8	73	11	LOWERBD NONBASIC
71	k1	n03	60	1	0	XK103	.	.	0	0	-127	74	12	LOWERBD NONBASIC
72	l1	n03	60	1	0	XL103	.	.	0	0	-157	75	13	LOWERBD NONBASIC
73	a1	n04	32	1	0	XA104	.	.	0	0	-451	76	2	LOWERBD NONBASIC
74	b1	n04	60	1	0	XB104	.	.	0	0	-60	77	3	LOWERBD NONBASIC
75	c1	n04	60	1	0	XC104	.	.	1	60	.	78	4	NONKEY ARC BASIC
76	d1	n04	60	1	0	XD104	.	.	0	0	-30	79	5	LOWERBD NONBASIC
77	e1	n04	60	1	0	XE104	.	.	0	0	-60	80	6	LOWERBD NONBASIC
78	f1	n04	90	1	0	XF104	.	.	0	0	.	81	7	KEY_ARC BASIC
79	g1	n04	90	1	0	XG104	.	.	0	0	.	82	8	NONKEY ARC BASIC
80	h1	n04	90	1	0	XH104	.	.	0	0	0	83	9	LOWERBD NONBASIC
81	i1	n04	88	1	0	XI104	.	.	0	0	.	84	10	NONKEY ARC BASIC
82	j1	n04	60	1	0	XJ104	.	.	0	0	-16	85	11	LOWERBD NONBASIC
83	k1	n04	60	1	0	XK104	.	.	0	0	-150	86	12	LOWERBD NONBASIC
84	l1	n04	60	1	0	XL104	.	.	0	0	-180	87	13	LOWERBD NONBASIC
85	a1	n05	264	1	0	XA105	.	.	0	0	.	88	2	KEY_ARC BASIC
86	b1	n05	156	1	0	XB105	.	.	0	0	-87	89	3	LOWERBD NONBASIC
87	c1	n05	242	1	0	XC105	.	.	1	242	.	90	4	NONKEY ARC BASIC
88	d1	n05	203	1	0	XD105	.	.	0	0	.	91	5	NONKEY ARC BASIC
89	e1	n05	162	1	0	XE105	.	.	0	0	-12	92	6	LOWERBD NONBASIC
90	f1	n05	178	1	0	XF105	.	.	0	0	.	93	7	NONKEY ARC BASIC
91	g1	n05	162	1	0	XG105	.	.	0	0	-34	94	8	LOWERBD NONBASIC
92	h1	n05	169	1	0	XH105	.	.	0	0	-59	95	9	LOWERBD NONBASIC
93	i1	n05	150	1	0	XI105	.	.	0	0	-12	96	10	LOWERBD NONBASIC
94	j1	n05	150	1	0	XJ105	.	.	0	0	.	97	11	NONKEY ARC BASIC
95	k1	n05	238	1	0	XK105	.	.	0	0	-46	98	12	LOWERBD NONBASIC
96	l1	n05	241	1	0	XL105	.	.	0	0	-73	99	13	LOWERBD NONBASIC
97	a1	n06	300	1	0	XA106	.	.	0	0	.	100	2	KEY_ARC BASIC
98	b1	n06	157	1	0	XB106	.	.	0	0	-37	101	3	LOWERBD NONBASIC
99	c1	n06	218	1	0	XC106	.	.	1	218	.	102	4	NONKEY ARC BASIC
100	d1	n06	185	1	0	XD106	.	.	0	0	.	103	5	NONKEY ARC BASIC
101	e1	n06	155	1	0	XE106	.	.	0	0	-34	104	6	LOWERBD NONBASIC
102	f1	n06	171	1	0	XF106	.	.	0	0	-17	105	7	LOWERBD NONBASIC
103	g1	n06	160	1	0	XG106	.	.	0	0	.	106	8	NONKEY ARC BASIC
104	h1	n06	165	1	0	XH106	.	.	0	0	-25	107	9	LOWERBD NONBASIC
105	i1	n06	149	1	0	XI106	.	.	0	0	-4	108	10	LOWERBD NONBASIC
106	j1	n06	152	1	0	XJ106	.	.	0	0	.	109	11	NONKEY ARC BASIC
107	k1	n06	239	1	0	XK106	.	.	0	0	-64	110	12	LOWERBD NONBASIC
108	l1	n06	287	1	0	XL106	.	.	0	0	-29	111	13	LOWERBD NONBASIC
109	a1	n07	300	1	0	XA107	.	.	0	0	.	112	2	KEY_ARC BASIC
110	b1	n07	188	1	0	XB107	.	.	0	0	-72	113	3	LOWERBD NONBASIC
111	c1	n07	292	1	0	XC107	.	.	1	292	.	114	4	NONKEY ARC BASIC
112	d1	n07	229	1	0	XD107	.	.	0	0	.	115	5	NONKEY ARC BASIC
113	e1	n07	189	1	0	XE107	.	.	0	0	-68	116	6	LOWERBD NONBASIC
114	f1	n07	202	1	0	XF107	.	.	0	0	-38	117	7	LOWERBD NONBASIC
115	g1	n07	192	1	0	XG107	.	.	0	0	-59	118	8	LOWERBD NONBASIC
116	h1	n07	196	1	0	XH107	.	.	0	0	-30	119	9	LOWERBD NONBASIC
117	i1	n07	175	1	0	XI107	.	.	0	0	-5	120	10	LOWERBD NONBASIC
118	j1	n07	180	1	0	XJ107	.	.	0	0	.	121	11	NONKEY ARC BASIC
119	k1	n07	292	1	0	XK107	.	.	0	0	-22	122	12	LOWERBD NONBASIC
120	l1	n07	300	1	0	XL107	.	.	0	0	-44	123	13	LOWERBD NONBASIC

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121	a1	n08	300	1	0	XA108	.	.	0	0	-158	124	2	LOWERBD NONBASIC
122	b1	n08	190	1	0	XB108	.	.	0	0	-27	125	3	LOWERBD NONBASIC
123	c1	n08	272	1	0	XC108	.	.	1	272	.	126	4	NONKEY ARC BASIC
124	d1	n08	228	1	0	XD108	.	.	0	0	.	127	5	NONKEY ARC BASIC
125	e1	n08	193	1	0	XE108	.	.	0	0	-48	128	6	LOWERBD NONBASIC
126	f1	n08	209	1	0	XF108	.	.	0	0	.	129	7	NONKEY ARC BASIC
127	g1	n08	195	1	0	XG108	.	.	0	0	-51	130	8	LOWERBD NONBASIC
128	h1	n08	202	1	0	XH108	.	.	0	0	-31	131	9	LOWERBD NONBASIC
129	i1	n08	183	1	0	XI108	.	.	0	0	-5	132	10	LOWERBD NONBASIC
130	j1	n08	187	1	0	XJ108	.	.	0	0	.	133	11	NONKEY ARC BASIC
131	k1	n08	300	1	0	XK108	.	.	0	0	.	134	12	NONKEY ARC BASIC
132	l1	n08	351	1	0	XL108	.	.	0	0	.	135	13	KEY_ARC BASIC
133	a1	n09	300	1	0	XA109	.	.	0	0	.	136	2	KEY_ARC BASIC
134	b1	n09	156	1	0	XB109	.	.	0	0	-23	137	3	LOWERBD NONBASIC
135	c1	n09	213	1	0	XC109	.	.	1	213	.	138	4	NONKEY ARC BASIC
136	d1	n09	179	1	0	XD109	.	.	0	0	.	139	5	NONKEY ARC BASIC
137	e1	n09	158	1	0	XE109	.	.	0	0	-62	140	6	LOWERBD NONBASIC
138	f1	n09	169	1	0	XF109	.	.	0	0	-29	141	7	LOWERBD NONBASIC
139	g1	n09	159	1	0	XG109	.	.	0	0	-40	142	8	LOWERBD NONBASIC
140	h1	n09	159	1	0	XH109	.	.	0	0	-26	143	9	LOWERBD NONBASIC
141	i1	n09	150	1	0	XI109	.	.	0	0	-13	144	10	LOWERBD NONBASIC
142	j1	n09	142	1	0	XJ109	.	.	0	0	-16	145	11	LOWERBD NONBASIC
143	k1	n09	227	1	0	XK109	.	.	0	0	-81	146	12	LOWERBD NONBASIC
144	l1	n09	261	1	0	XL109	.	.	0	0	-77	147	13	LOWERBD NONBASIC
145	a1	n10	300	1	0	XA110	.	.	0	0	.	148	2	KEY_ARC BASIC
146	b1	n10	156	1	0	XB110	.	.	0	0	-74	149	3	LOWERBD NONBASIC
147	c1	n10	217	1	0	XC110	.	.	1	217	.	150	4	NONKEY ARC BASIC
148	d1	n10	184	1	0	XD110	.	.	0	0	.	151	5	NONKEY ARC BASIC
149	e1	n10	158	1	0	XE110	.	.	0	0	-33	152	6	LOWERBD NONBASIC
150	f1	n10	171	1	0	XF110	.	.	0	0	.	153	7	NONKEY ARC BASIC
151	g1	n10	158	1	0	XG110	.	.	0	0	-83	154	8	LOWERBD NONBASIC
152	h1	n10	163	1	0	XH110	.	.	0	0	-34	155	9	LOWERBD NONBASIC
153	i1	n10	149	1	0	XI110	.	.	0	0	-14	156	10	LOWERBD NONBASIC
154	j1	n10	151	1	0	XJ110	.	.	0	0	.	157	11	NONKEY ARC BASIC
155	k1	n10	241	1	0	XK110	.	.	0	0	-44	158	12	LOWERBD NONBASIC
156	l1	n10	288	1	0	XL110	.	.	0	0	-27	159	13	LOWERBD NONBASIC
157	a1	n11	300	1	0	XA111	.	.	0	0	-69	160	2	LOWERBD NONBASIC
158	b1	n11	180	1	0	XB111	.	.	0	0	-111	161	3	LOWERBD NONBASIC
159	c1	n11	295	1	0	XC111	.	.	1	295	.	162	4	NONKEY ARC BASIC
160	d1	n11	237	1	0	XD111	.	.	0	0	.	163	5	NONKEY ARC BASIC
161	e1	n11	180	1	0	XE111	.	.	0	0	-34	164	6	LOWERBD NONBASIC
162	f1	n11	189	1	0	XF111	.	.	0	0	-24	165	7	LOWERBD NONBASIC
163	g1	n11	180	1	0	XG111	.	.	0	0	-64	166	8	LOWERBD NONBASIC
164	h1	n11	180	1	0	XH111	.	.	0	0	-54	167	9	LOWERBD NONBASIC
165	i1	n11	180	1	0	XI111	.	.	0	0	.	168	10	NONKEY ARC BASIC
166	j1	n11	168	1	0	XJ111	.	.	0	0	-6	169	11	LOWERBD NONBASIC
167	k1	n11	300	1	0	XK111	.	.	0	0	.	170	12	KEY_ARC BASIC
168	l1	n11	300	1	0	XL111	.	.	0	0	-38	171	13	LOWERBD NONBASIC
169	a1	n12	300	1	0	XA112	.	.	0	0	.	172	2	KEY_ARC BASIC
170	b1	n12	188	1	0	XB112	.	.	0	0	-52	173	3	LOWERBD NONBASIC
171	c1	n12	289	1	0	XC112	.	.	1	289	.	174	4	NONKEY ARC BASIC
172	d1	n12	235	1	0	XD112	.	.	0	0	.	175	5	NONKEY ARC BASIC
173	e1	n12	198	1	0	XE112	.	.	0	0	-68	176	6	LOWERBD NONBASIC
174	f1	n12	212	1	0	XF112	.	.	0	0	-51	177	7	LOWERBD NONBASIC
175	g1	n12	200	1	0	XG112	.	.	0	0	-60	178	8	LOWERBD NONBASIC
176	h1	n12	208	1	0	XH112	.	.	0	0	-34	179	9	LOWERBD NONBASIC
177	i1	n12	181	1	0	XI112	.	.	0	0	-27	180	10	LOWERBD NONBASIC
178	j1	n12	182	1	0	XJ112	.	.	0	0	.	181	11	NONKEY ARC BASIC
179	k1	n12	295	1	0	XK112	.	.	0	0	-21	182	12	LOWERBD NONBASIC
180	l1	n12	300	1	0	XL112	.	.	0	0	-46	183	13	LOWERBD NONBASIC

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181	a1	n13	300	1	0	XA113	.	.	0	0	.	184	2	KEY_ARC BASIC
182	b1	n13	191	1	0	XB113	.	.	0	0	.	185	3	NONKEY ARC BASIC
183	c1	n13	291	1	0	XC113	.	.	1	291	.	186	4	NONKEY ARC BASIC
184	d1	n13	238	1	0	XD113	.	.	0	0	.	187	5	NONKEY ARC BASIC
185	e1	n13	191	1	0	XE113	.	.	0	0	-19	188	6	LOWERBD NONBASIC
186	f1	n13	209	1	0	XF113	.	.	0	0	.	189	7	NONKEY ARC BASIC
187	g1	n13	193	1	0	XG113	.	.	0	0	-47	190	8	LOWERBD NONBASIC
188	h1	n13	199	1	0	XH113	.	.	0	0	-17	191	9	LOWERBD NONBASIC
189	i1	n13	180	1	0	XI113	.	.	0	0	-16	192	10	LOWERBD NONBASIC
190	j1	n13	184	1	0	XJ113	.	.	0	0	.	193	11	NONKEY ARC BASIC
191	k1	n13	293	1	0	XK113	.	.	0	0	-11	194	12	LOWERBD NONBASIC
192	l1	n13	299	1	0	XL113	.	.	0	0	-35	195	13	LOWERBD NONBASIC
193	a1	n14	300	1	0	XA114	.	.	0	0	.	196	2	KEY_ARC BASIC
194	b1	n14	180	1	0	XB114	.	.	0	0	-2	197	3	LOWERBD NONBASIC
195	c1	n14	293.	1	0	XC114	.	.	1	293	.	198	4	NONKEY ARC BASIC
196	d1	n14	220	1	0	XD114	.	.	0	0	.	199	5	NONKEY ARC BASIC
197	e1	n14	184	1	0	XE114	.	.	0	0	-17	200	6	LOWERBD NONBASIC
198	f1	n14	200	1	0	XF114	.	.	0	0	.	201	7	NONKEY ARC BASIC
199	g1	n14	188	1	0	XG114	.	.	0	0	-45	202	8	LOWERBD NONBASIC
200	h1	n14	193	1	0	XH114	.	.	0	0	-28	203	9	LOWERBD NONBASIC
201	i1	n14	173	1	0	XI114	.	.	0	0	.	204	10	NONKEY ARC BASIC
202	j1	n14	175	1	0	XJ114	.	.	0	0	.	205	11	NONKEY ARC BASIC
203	k1	n14	298	1	0	XK114	.	.	0	0	-11	206	12	LOWERBD NONBASIC
204	l1	n14	300	1	0	XL114	.	.	0	0	-25	207	13	LOWERBD NONBASIC
205	a1	n15	300	1	0	XA115	.	.	0	0	.	208	2	KEY_ARC BASIC
206	b1	n15	184	1	0	XB115	.	.	0	0	.	209	3	NONKEY ARC BASIC
207	c1	n15	290	1	0	XC115	.	.	1	290	.	210	4	NONKEY ARC BASIC
208	d1	n15	224	1	0	XD115	.	.	0	0	.	211	5	NONKEY ARC BASIC
209	e1	n15	186	1	0	XE115	.	.	0	0	-40	212	6	LOWERBD NONBASIC
210	f1	n15	202	1	0	XF115	.	.	0	0	-23	213	7	LOWERBD NONBASIC
211	g1	n15	188	1	0	XG115	.	.	0	0	-42	214	8	LOWERBD NONBASIC
212	h1	n15	192	1	0	XH115	.	.	0	0	-25	215	9	LOWERBD NONBASIC
213	i1	n15	174	1	0	XI115	.	.	0	0	-14	216	10	LOWERBD NONBASIC
214	j1	n15	176	1	0	XJ115	.	.	0	0	-10	217	11	LOWERBD NONBASIC
215	k1	n15	294	1	0	XK115	.	.	0	0	-40	218	12	LOWERBD NONBASIC
216	l1	n15	298	1	0	XL115	.	.	0	0	-66	219	13	LOWERBD NONBASIC
217	a1	n16	300	1	0	XA116	.	.	0	0	.	220	2	KEY_ARC BASIC
218	b1	n16	180	1	0	XB116	.	.	0	0	-73	221	3	LOWERBD NONBASIC
219	c1	n16	292	1	0	XC116	.	.	1	292	.	222	4	NONKEY ARC BASIC
220	d1	n16	219	1	0	XD116	.	.	0	0	.	223	5	NONKEY ARC BASIC
221	e1	n16	183	1	0	XE116	.	.	0	0	-60	224	6	LOWERBD NONBASIC
222	f1	n16	199	1	0	XF116	.	.	0	0	.	225	7	NONKEY ARC BASIC
223	g1	n16	186	1	0	XG116	.	.	0	0	-75	226	8	LOWERBD NONBASIC
224	h1	n16	190	1	0	XH116	.	.	0	0	-59	227	9	LOWERBD NONBASIC
225	i1	n16	171	1	0	XI116	.	.	0	0	-42	228	10	LOWERBD NONBASIC
226	j1	n16	173	1	0	XJ116	.	.	0	0	-30	229	11	LOWERBD NONBASIC
227	k1	n16	294	1	0	XK116	.	.	0	0	-43	230	12	LOWERBD NONBASIC
228	l1	n16	299	1	0	XL116	.	.	0	0	-82	231	13	LOWERBD NONBASIC
229	a2	n17	0	1	0	XA217	.	.	0	0	.	232	15	NONKEY ARC BASIC
230	b2	n17	146	1	0	XB217	.	.	0	0	.	233	16	NONKEY ARC BASIC
231	c2	n17	73	1	0	XC217	.	.	1	73	.	234	17	NONKEY ARC BASIC
232	d2	n17	112	1	0	XD217	.	.	0	0	-33	235	18	LOWERBD NONBASIC
233	e2	n17	144	1	0	XE217	.	.	0	0	-34	236	19	LOWERBD NONBASIC
234	f2	n17	129	1	0	XF217	.	.	0	0	.	237	20	NONKEY ARC BASIC
235	g2	n17	140	1	0	XG217	.	.	0	0	.	238	21	NONKEY ARC BASIC
236	h2	n17	135	1	0	XH217	.	.	0	0	.	239	22	NONKEY ARC BASIC
237	i2	n17	154	1	0	XI217	.	.	0	0	.	240	23	KEY_ARC BASIC
238	j2	n17	152	1	0	XJ217	.	.	0	0	-4	241	24	LOWERBD NONBASIC
239	k2	n17	38	1	0	XK217	.	.	0	0	-229	242	25	LOWERBD NONBASIC
240	l2	n17	0	1	0	XL217	.	.	0	0	-500000167	243	26	LOWERBD NONBASIC

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241	a2	n18	0	1	0	XA218	.	.	0	0	-535	244	15	LOWERBD NONBASIC
242	b2	n18	168	1	0	XB218	.	.	0	0	.	245	16	NONKEY ARC BASIC
243	c2	n18	122	1	0	XC218	.	.	1	122	.	246	17	NONKEY ARC BASIC
244	d2	n18	145	1	0	XD218	.	.	0	0	-19	247	18	LOWERBD NONBASIC
245	e2	n18	169	1	0	XE218	.	.	0	0	-3	248	19	LOWERBD NONBASIC
246	f2	n18	156	1	0	XF218	.	.	0	0	.	249	20	NONKEY ARC BASIC
247	g2	n18	164	1	0	XG218	.	.	0	0	.	250	21	NONKEY ARC BASIC
248	h2	n18	160	1	0	XH218	.	.	0	0	.	251	22	NONKEY ARC BASIC
249	i2	n18	176	1	0	XI218	.	.	0	0	.	252	23	KEY_ARC BASIC
250	j2	n18	175	1	0	XJ218	.	.	0	0	.	253	24	NONKEY ARC BASIC
251	k2	n18	107	1	0	XK218	.	.	0	0	-179	254	25	LOWERBD NONBASIC
252	l2	n18	91	1	0	XL218	.	.	0	0	-500000095	255	26	LOWERBD NONBASIC
253	a2	n19	0	1	0	XA219	.	.	0	0	-542	256	15	LOWERBD NONBASIC
254	b2	n19	182	1	0	XB219	.	.	0	0	-13	257	16	LOWERBD NONBASIC
255	c2	n19	151	1	0	XC219	.	.	1	151	.	258	17	NONKEY ARC BASIC
256	d2	n19	166	1	0	XD219	.	.	0	0	-8	259	18	LOWERBD NONBASIC
257	e2	n19	180	1	0	XE219	.	.	0	0	.	260	19	NONKEY ARC BASIC
258	f2	n19	174	1	0	XF219	.	.	0	0	.	261	20	NONKEY ARC BASIC
259	g2	n19	180	1	0	XG219	.	.	0	0	.	262	21	NONKEY ARC BASIC
260	h2	n19	177	1	0	XH219	.	.	0	0	-2	263	22	LOWERBD NONBASIC
261	i2	n19	187	1	0	XI219	.	.	0	0	.	264	23	KEY_ARC BASIC
262	j2	n19	185	1	0	XJ219	.	.	0	0	.	265	24	NONKEY ARC BASIC
263	k2	n19	144	1	0	XK219	.	.	0	0	-152	266	25	LOWERBD NONBASIC
264	l2	n19	135	1	0	XL219	.	.	0	0	-500000061	267	26	LOWERBD NONBASIC
265	a2	n20	60	1	0	XA220	.	.	0	0	.	268	15	KEY_ARC BASIC
266	b2	n20	60	1	0	XB220	.	.	0	0	.	269	16	NONKEY ARC BASIC
267	c2	n20	60	1	0	XC220	.	.	1	60	.	270	17	NONKEY ARC BASIC
268	d2	n20	60	1	0	XD220	.	.	0	0	.	271	18	NONKEY ARC BASIC
269	e2	n20	60	1	0	XE220	.	.	0	0	.	272	19	NONKEY ARC BASIC
270	f2	n20	60	1	0	XF220	.	.	0	0	.	273	20	NONKEY ARC BASIC
271	g2	n20	60	1	0	XG220	.	.	0	0	0	274	21	LOWERBD NONBASIC
272	h2	n20	60	1	0	XH220	.	.	0	0	.	275	22	NONKEY ARC BASIC
273	i2	n20	60	1	0	XI220	.	.	0	0	.	276	23	NONKEY ARC BASIC
274	j2	n20	60	1	0	XJ220	.	.	0	0	-12	277	24	LOWERBD NONBASIC
275	k2	n20	60	1	0	XK220	.	.	0	0	-123	278	25	LOWERBD NONBASIC
276	l2	n20	60	1	0	XL220	.	.	0	0	-500000023	279	26	LOWERBD NONBASIC
277	a2	n21	36	1	0	XA221	.	.	0	0	-422	280	15	LOWERBD NONBASIC
278	b2	n21	187	1	0	XB221	.	.	0	0	.	281	16	NONKEY ARC BASIC
279	c2	n21	207	1	0	XC221	.	.	1	207	.	282	17	NONKEY ARC BASIC
280	d2	n21	212	1	0	XD221	.	.	0	0	.	283	18	NONKEY ARC BASIC
281	e2	n21	201	1	0	XE221	.	.	0	0	-62	284	19	LOWERBD NONBASIC
282	f2	n21	215	1	0	XF221	.	.	0	0	.	285	20	NONKEY ARC BASIC
283	g2	n21	219	1	0	XG221	.	.	0	0	.	286	21	KEY_ARC BASIC
284	h2	n21	217	1	0	XH221	.	.	0	0	.	287	22	NONKEY ARC BASIC
285	i2	n21	164	1	0	XI221	.	.	0	0	-65	288	23	LOWERBD NONBASIC
286	j2	n21	170	1	0	XJ221	.	.	0	0	-71	289	24	LOWERBD NONBASIC
287	k2	n21	203	1	0	XK221	.	.	0	0	-149	290	25	LOWERBD NONBASIC
288	l2	n21	200	1	0	XL221	.	.	0	0	-500000052	291	26	LOWERBD NONBASIC
289	a2	n22	61	1	0	XA222	.	.	0	0	-340	292	15	LOWERBD NONBASIC
290	b2	n22	224	1	0	XB222	.	.	0	0		293	16	KEY_ARC BASIC
291	c2	n22	197	1	0	XC222	.	.	1	197	.	294	17	NONKEY ARC BASIC
292	d2	n22	212	1	0	XD222	.	.	0	0	.	295	18	NONKEY ARC BASIC
293	e2	n22	214	1	0	XE222	.	.	0	0	.	296	19	NONKEY ARC BASIC
294	f2	n22	212	1	0	XF222	.	.	0	0	.	297	20	NONKEY ARC BASIC
295	g2	n22	211	1	0	XG222	.	.	0	0	-32	298	21	LOWERBD NONBASIC
296	h2	n22	212	1	0	XH222	.	.	0	0	.	299	22	NONKEY ARC BASIC
297	i2	n22	213	1	0	XI222	.	.	0	0	.	300	23	NONKEY ARC BASIC
298	j2	n22	214	1	0	XJ222	.	.	0	0	.	301	24	NONKEY ARC BASIC
299	k2	n22	196	1	0	XK222	.	.	0	0	-129	302	25	LOWERBD NONBASIC
300	l2	n22	190	1	0	XL222	.	.	0	0	-500000035	303	26	LOWERBD NONBASIC

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301	a2	n23	300	1	0	XA223	.	.	0	0	.	304	15	KEY_ARC BASIC
302	b2	n23	240	1	0	XB223	.	.	0	0	.	305	16	NONKEY ARC BASIC
303	c2	n23	251	1	0	XC223	.	.	1	251	.	306	17	NONKEY ARC BASIC
304	d2	n23	246	1	0	XD223	.	.	0	0	-8	307	18	LOWERBD NONBASIC
305	e2	n23	238	1	0	XE223	.	.	0	0	.	308	19	NONKEY ARC BASIC
306	f2	n23	242	1	0	XF223	.	.	0	0	.	309	20	NONKEY ARC BASIC
307	g2	n23	240	1	0	XG223	.	.	0	0	.	310	21	NONKEY ARC BASIC
308	h2	n23	241	1	0	XH223	.	.	0	0	-4	311	22	LOWERBD NONBASIC
309	i2	n23	237	1	0	XI223	.	.	0	0	.	312	23	NONKEY ARC BASIC
310	j2	n23	237	1	0	XJ223	.	.	0	0	.	313	24	NONKEY ARC BASIC
311	k2	n23	256	1	0	XK223	.	.	0	0	-92	314	25	LOWERBD NONBASIC
312	l2	n23	260	1	0	XL223	.	.	0	0	-499999988	315	26	LOWERBD NONBASIC
313	a2	n24	300	1	0	XA224	.	.	0	0	.	316	15	KEY_ARC BASIC
314	b2	n24	239	1	0	XB224	.	.	0	0	.	317	16	NONKEY ARC BASIC
315	c2	n24	252	1	0	XC224	.	.	1	252	.	318	17	NONKEY ARC BASIC
316	d2	n24	246	1	0	XD224	.	.	0	0	-5	319	18	LOWERBD NONBASIC
317	e2	n24	240	1	0	XE224	.	.	0	0	-21	320	19	LOWERBD NONBASIC
318	f2	n24	243	1	0	XF224	.	.	0	0	-28	321	20	LOWERBD NONBASIC
319	g2	n24	240	1	0	XG224	.	.	0	0	.	322	21	NONKEY ARC BASIC
320	h2	n24	241	1	0	XH224	.	.	0	0	-6	323	22	LOWERBD NONBASIC
321	i2	n24	238	1	0	XI224	.	.	0	0	.	324	23	NONKEY ARC BASIC
322	j2	n24	239	1	0	XJ224	.	.	0	0	.	325	24	NONKEY ARC BASIC
323	k2	n24	255	1	0	XK224	.	.	0	0	-95	326	25	LOWERBD NONBASIC
324	l2	n24	261	1	0	XL224	.	.	0	0	-499999989	327	26	LOWERBD NONBASIC
325	a2	n25	300	1	0	XA225	.	.	0	0	-153	328	15	LOWERBD NONBASIC
326	b2	n25	214	1	0	XB225	.	.	0	0	.	329	16	NONKEY ARC BASIC
327	c2	n25	290	1	0	XC225	.	.	1	290	.	330	17	NONKEY ARC BASIC
328	d2	n25	277	1	0	XD225	.	.	0	0	.	331	18	NONKEY ARC BASIC
329	e2	n25	219	1	0	XE225	.	.	0	0	.	332	19	NONKEY ARC BASIC
330	f2	n25	250	1	0	XF225	.	.	0	0	.	333	20	NONKEY ARC BASIC
331	g2	n25	224	1	0	XG225	.	.	0	0	.	334	21	NONKEY ARC BASIC
332	h2	n25	232	1	0	XH225	.	.	0	0	.	335	22	NONKEY ARC BASIC
333	i2	n25	200	1	0	XI225	.	.	0	0	.	336	23	NONKEY ARC BASIC
334	j2	n25	205	1	0	XJ225	.	.	0	0	.	337	24	NONKEY ARC BASIC
335	k2	n25	300	1	0	XK225	.	.	0	0	.	338	25	KEY_ARC BASIC
336	l2	n25	300	1	0	XL225	.	.	0	0	-499999900	339	26	LOWERBD NONBASIC
337	a2	n26	300	1	0	XA226	.	.	0	0	.	340	15	KEY_ARC BASIC
338	b2	n26	163	1	0	XB226	.	.	0	0	.	341	16	NONKEY ARC BASIC
339	c2	n26	215	1	0	XC226	.	.	1	215	.	342	17	NONKEY ARC BASIC
340	d2	n26	185	1	0	XD226	.	.	0	0	.	343	18	NONKEY ARC BASIC
341	e2	n26	163	1	0	XE226	.	.	0	0	-41	344	19	LOWERBD NONBASIC
342	f2	n26	173	1	0	XF226	.	.	0	0	-41	345	20	LOWERBD NONBASIC
343	g2	n26	166	1	0	XG226	.	.	0	0	.	346	21	NONKEY ARC BASIC
344	h2	n26	169	1	0	XH226	.	.	0	0	-21	347	22	LOWERBD NONBASIC
345	i2	n26	153	1	0	XI226	.	.	0	0	-17	348	23	LOWERBD NONBASIC
346	j2	n26	155	1	0	XJ226	.	.	0	0	-27	349	24	LOWERBD NONBASIC
347	k2	n26	234	1	0	XK226	.	.	0	0	-59	350	25	LOWERBD NONBASIC
348	l2	n26	254	1	0	XL226	.	.	0	0	-499999939	351	26	LOWERBD NONBASIC
349	a2	n27	300	1	0	XA227	.	.	0	0	.	352	15	KEY_ARC BASIC
350	b2	n27	157	1	0	XB227	.	.	0	0	.	353	16	NONKEY ARC BASIC
351	c2	n27	215	1	0	XC227	.	.	1	215	.	354	17	NONKEY ARC BASIC
352	d2	n27	180	1	0	XD227	.	.	0	0	.	355	18	NONKEY ARC BASIC
353	e2	n27	155	1	0	XE227	.	.	0	0	-17	356	19	LOWERBD NONBASIC
354	f2	n27	166	1	0	XF227	.	.	0	0	-16	357	20	LOWERBD NONBASIC
355	g2	n27	154	1	0	XG227	.	.	0	0	.	358	21	NONKEY ARC BASIC
356	h2	n27	158	1	0	XH227	.	.	0	0	.	359	22	NONKEY ARC BASIC
357	i2	n27	144	1	0	XI227	.	.	0	0	.	360	23	NONKEY ARC BASIC
358	j2	n27	150	1	0	XJ227	.	.	0	0	.	361	24	NONKEY ARC BASIC
359	k2	n27	232	1	0	XK227	.	.	0	0	-29	362	25	LOWERBD NONBASIC
360	l2	n27	265	1	0	XL227	.	.	0	0	-499999896	363	26	LOWERBD NONBASIC

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361	a2	n28	300	1	0	XA228	.	.	0	0	-212	364	15	LOWERBD NONBASIC
362	b2	n28	245	1	0	XB228	.	.	0	0	.	365	16	NONKEY ARC BASIC
363	c2	n28	296	1	0	XC228	.	.	1	296	.	366	17	NONKEY ARC BASIC
364	d2	n28	288	1	0	XD228	.	.	0	0	.	367	18	NONKEY ARC BASIC
365	e2	n28	251	1	0	XE228	.	.	0	0	.	368	19	NONKEY ARC BASIC
366	f2	n28	280	1	0	XF228	.	.	0	0	.	369	20	NONKEY ARC BASIC
367	g2	n28	255	1	0	XG228	.	.	0	0	.	370	21	KEY_ARC BASIC
368	h2	n28	267	1	0	XH228	.	.	0	0	-14	371	22	LOWERBD NONBASIC
369	i2	n28	219	1	0	XI228	.	.	0	0	-42	372	23	LOWERBD NONBASIC
370	j2	n28	224	1	0	XJ228	.	.	0	0	-49	373	24	LOWERBD NONBASIC
371	k2	n28	300	1	0	XK228	.	.	0	0	-84	374	25	LOWERBD NONBASIC
372	l2	n28	300	1	0	XL228	.	.	0	0	-499999984	375	26	LOWERBD NONBASIC
373	a2	n29	300	1	0	XA229	.	.	0	0	-136	376	15	LOWERBD NONBASIC
374	b2	n29	168	1	0	XB229	.	.	0	0	-25	377	16	LOWERBD NONBASIC
375	c2	n29	243	1	0	XC229	.	.	1	243	.	378	17	NONKEY ARC BASIC
376	d2	n29	202	1	0	XD229	.	.	0	0	-7	379	18	LOWERBD NONBASIC
377	e2	n29	173	1	0	XE229	.	.	0	0	-33	380	19	LOWERBD NONBASIC
378	f2	n29	186	1	0	XF229	.	.	0	0	-30	381	20	LOWERBD NONBASIC
379	g2	n29	174	1	0	XG229	.	.	0	0	.	382	21	NONKEY ARC BASIC
380	h2	n29	177	1	0	XH229	.	.	0	0	-15	383	22	LOWERBD NONBASIC
381	i2	n29	162	1	0	XI229	.	.	0	0	-10	384	23	LOWERBD NONBASIC
382	j2	n29	162	1	0	XJ229	.	.	0	0	-22	385	24	LOWERBD NONBASIC
383	k2	n29	295	1	0	XK229	.	.	0	0	.	386	25	KEY_ARC BASIC
384	l2	n29	299	1	0	XL229	.	.	0	0	-499999896	387	26	LOWERBD NONBASIC
385	a2	n30	300	1	0	XA230	.	.	0	0	-79	388	15	LOWERBD NONBASIC
386	b2	n30	168	1	0	XB230	.	.	0	0	-25	389	16	LOWERBD NONBASIC
387	c2	n30	244	1	0	XC230	.	.	1	244	.	390	17	NONKEY ARC BASIC
388	d2	n30	202	1	0	XD230	.	.	0	0	.	391	18	NONKEY ARC BASIC
389	e2	n30	172	1	0	XE230	.	.	0	0	-34	392	19	LOWERBD NONBASIC
390	f2	n30	185	1	0	XF230	.	.	0	0	-31	393	20	LOWERBD NONBASIC
391	g2	n30	172	1	0	XG230	.	.	0	0	0	394	21	LOWERBD NONBASIC
392	h2	n30	178	1	0	XH230	.	.	0	0	.	395	22	NONKEY ARC BASIC
393	i2	n30	161	1	0	XI230	.	.	0	0	-11	396	23	LOWERBD NONBASIC
394	j2	n30	162	1	0	XJ230	.	.	0	0	-22	397	24	LOWERBD NONBASIC
395	k2	n30	295	1	0	XK230	.	.	0	0	.	398	25	KEY_ARC BASIC
396	l2	n30	298	1	0	XL230	.	.	0	0	-499999897	399	26	LOWERBD NONBASIC
397	a2	n31	300	1	0	XA231	.	.	0	0	-96	400	15	LOWERBD NONBASIC
398	b2	n31	191	1	0	XB231	.	.	0	0	.	401	16	NONKEY ARC BASIC
399	c2	n31	289	1	0	XC231	.	.	1	289	.	402	17	NONKEY ARC BASIC
400	d2	n31	237	1	0	XD231	.	.	0	0	.	403	18	NONKEY ARC BASIC
401	e2	n31	196	1	0	XE231	.	.	0	0	-8	404	19	LOWERBD NONBASIC
402	f2	n31	214	1	0	XF231	.	.	0	0	.	405	20	NONKEY ARC BASIC
403	g2	n31	198	1	0	XG231	.	.	0	0	.	406	21	NONKEY ARC BASIC
404	h2	n31	205	1	0	XH231	.	.	0	0	.	407	22	NONKEY ARC BASIC
405	i2	n31	180	1	0	XI231	.	.	0	0	.	408	23	NONKEY ARC BASIC
406	j2	n31	182	1	0	XJ231	.	.	0	0	.	409	24	NONKEY ARC BASIC
407	k2	n31	293	1	0	XK231	.	.	0	0	.	410	25	KEY_ARC BASIC
408	l2	n31	298	1	0	XL231	.	.	0	0	-499999895	411	26	LOWERBD NONBASIC
409	a2	n32	300	1	0	XA232	.	.	0	0	-203	412	15	LOWERBD NONBASIC
410	b2	n32	181	1	0	XB232	.	.	0	0	-12	413	16	LOWERBD NONBASIC
411	c2	n32	292	1	0	XC232	.	.	1	292	.	414	17	NONKEY ARC BASIC
412	d2	n32	221	1	0	XD232	.	.	0	0	.	415	18	NONKEY ARC BASIC
413	e2	n32	185	1	0	XE232	.	.	0	0	-21	416	19	LOWERBD NONBASIC
414	f2	n32	200	1	0	XF232	.	.	0	0	.	417	20	NONKEY ARC BASIC
415	g2	n32	186	1	0	XG232	.	.	0	0	.	418	21	NONKEY ARC BASIC
416	h2	n32	192	1	0	XH232	.	.	0	0	.	419	22	NONKEY ARC BASIC
417	i2	n32	174	1	0	XI232	.	.	0	0	.	420	23	NONKEY ARC BASIC
418	j2	n32	176	1	0	XJ232	.	.	0	0	-8	421	24	LOWERBD NONBASIC
419	k2	n32	295	1	0	XK232	.	.	0	0	.	422	25	KEY_ARC BASIC
420	l2	n32	298	1	0	XL232	.	.	0	0	-499999897	423	26	LOWERBD NONBASIC

OBS	_FROM_	_TO_	_COST_	_CAPAC_	_LO_	_NAME_	_SUPPLY_	_DEMAND_	_FLOW_	_FCOST_	_RCOST_	_ANUMB_	_TNUMB_	_STATUS_
421	a3	n33	0	1	0	XA333	.	.	0	0	-860	424	28	LOWERBD NONBASIC
422	b3	n33	139	1	0	XB333	.	.	0	0	.	425	29	NONKEY ARC BASIC
423	c3	n33	47	1	0	XC333	.	.	1	47	.	426	30	NONKEY ARC BASIC
424	d3	n33	100	1	0	XD333	.	.	0	0	.	427	31	NONKEY ARC BASIC
425	e3	n33	134	1	0	XE333	.	.	0	0	.	428	32	NONKEY ARC BASIC
426	f3	n33	119	1	0	XF333	.	.	0	0	.	429	33	NONKEY ARC BASIC
427	g3	n33	132	1	0	XG333	.	.	0	0	.	430	34	NONKEY ARC BASIC
428	h3	n33	127	1	0	XH333	.	.	0	0	.	431	35	NONKEY ARC BASIC
429	i3	n33	148	1	0	XI333	.	.	0	0	.	432	36	KEY_ARC BASIC
430	j3	n33	144	1	0	XJ333	.	.	0	0	-4	433	37	LOWERBD NONBASIC
431	k3	n33	0	1	0	XK333	.	.	0	0	-148	434	38	LOWERBD NONBASIC
432	l3	n33	0	1	0	XL333	.	.	0	0	-100000147	435	39	LOWERBD NONBASIC
433	a3	n34	64	1	0	XA334	.	.	0	0	.	436	28	KEY_ARC BASIC
434	b3	n34	64	1	0	XB334	.	.	0	0	.	437	29	NONKEY ARC BASIC
435	c3	n34	64	1	0	XC334	.	.	1	64	.	438	30	NONKEY ARC BASIC
436	d3	n34	64	1	0	XD334	.	.	0	0	.	439	31	NONKEY ARC BASIC
437	e3	n34	64	1	0	XE334	.	.	0	0	.	440	32	NONKEY ARC BASIC
438	f3	n34	64	1	0	XF334	.	.	0	0	.	441	33	NONKEY ARC BASIC
439	g3	n34	64	1	0	XG334	.	.	0	0	.	442	34	NONKEY ARC BASIC
440	h3	n34	64	1	0	XH334	.	.	0	0	-12	443	35	LOWERBD NONBASIC
441	i3	n34	60	1	0	XI334	.	.	0	0	.	444	36	NONKEY ARC BASIC
442	j3	n34	56	1	0	XJ334	.	.	0	0	-4	445	37	LOWERBD NONBASIC
443	k3	n34	64	1	0	XK334	.	.	0	0	.	446	38	NONKEY ARC BASIC
444	l3	n34	64	1	0	XL334	.	.	0	0	-99999995	447	39	LOWERBD NONBASIC
445	a3	n35	62	1	0	XA335	.	.	0	0	.	448	28	NONKEY ARC BASIC
446	b3	n35	57	1	0	XB335	.	.	0	0	.	449	29	NONKEY ARC BASIC
447	c3	n35	59	1	0	XC335	.	.	1	59	.	450	30	NONKEY ARC BASIC
448	d3	n35	67	1	0	XD335	.	.	0	0	.	451	31	KEY_ARC BASIC
449	e3	n35	61	1	0	XE335	.	.	0	0	.	452	32	NONKEY ARC BASIC
450	f3	n35	61	1	0	XF335	.	.	0	0	.	453	33	NONKEY ARC BASIC
451	g3	n35	62	1	0	XG335	.	.	0	0	.	454	34	NONKEY ARC BASIC
452	h3	n35	62	1	0	XH335	.	.	0	0	.	455	35	NONKEY ARC BASIC
453	i3	n35	56	1	0	XI335	.	.	0	0	-7	456	36	LOWERBD NONBASIC
454	j3	n35	56	1	0	XJ335	.	.	0	0	-7	457	37	LOWERBD NONBASIC
455	k3	n35	62	1	0	XK335	.	.	0	0	-1	458	38	LOWERBD NONBASIC
456	l3	n35	55	1	0	XL335	.	.	0	0	-100000007	459	39	LOWERBD NONBASIC
457	a3	n36	60	1	0	XA336	.	.	0	0	.	460	28	NONKEY ARC BASIC
458	b3	n36	60	1	0	XB336	.	.	0	0	.	461	29	NONKEY ARC BASIC
459	c3	n36	60	1	0	XC336	.	.	1	60	.	462	30	NONKEY ARC BASIC
460	d3	n36	90	1	0	XD336	.	.	0	0	.	463	31	KEY_ARC BASIC
461	e3	n36	60	1	0	XE336	.	.	0	0	.	464	32	NONKEY ARC BASIC
462	f3	n36	90	1	0	XF336	.	.	0	0	.	465	33	NONKEY ARC BASIC
463	g3	n36	90	1	0	XG336	.	.	0	0	.	466	34	NONKEY ARC BASIC
464	h3	n36	90	1	0	XH336	.	.	0	0	.	467	35	NONKEY ARC BASIC
465	i3	n36	90	1	0	XI336	.	.	0	0	-2	468	36	LOWERBD NONBASIC
466	j3	n36	60	1	0	XJ336	.	.	0	0	-32	469	37	LOWERBD NONBASIC
467	k3	n36	60	1	0	XK336	.	.	0	0	-32	470	38	LOWERBD NONBASIC
468	l3	n36	60	1	0	XL336	.	.	0	0	-100000031	471	39	LOWERBD NONBASIC
469	a3	n37	300	1	0	XA337	.	.	0	0	.	472	28	KEY_ARC BASIC
470	b3	n37	243	1	0	XB337	.	.	0	0	.	473	29	NONKEY ARC BASIC
471	c3	n37	244	1	0	XC337	.	.	1	244	.	474	30	NONKEY ARC BASIC
472	d3	n37	244	1	0	XD337	.	.	0	0	.	475	31	NONKEY ARC BASIC
473	e3	n37	222	1	0	XE337	.	.	0	0	.	476	32	NONKEY ARC BASIC
474	f3	n37	244	1	0	XF337	.	.	0	0	-22	477	33	LOWERBD NONBASIC
475	g3	n37	244	1	0	XG337	.	.	0	0	.	478	34	NONKEY ARC BASIC
476	h3	n37	214	1	0	XH337	.	.	0	0	.	479	35	NONKEY ARC BASIC
477	i3	n37	183	1	0	XI337	.	.	0	0	-85	480	36	LOWERBD NONBASIC
478	j3	n37	243	1	0	XJ337	.	.	0	0	-25	481	37	LOWERBD NONBASIC
479	k3	n37	244	1	0	XK337	.	.	0	0	-24	482	38	LOWERBD NONBASIC
480	l3	n37	244	1	0	XL337	.	.	0	0	-100000023	483	39	LOWERBD NONBASIC

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481	a3	n38	214	1	0	XA338	.	.	0	0	.	484	28	KEY_ARC BASIC
482	b3	n38	148	1	0	XB338	.	.	0	0	.	485	29	NONKEY ARC BASIC
483	c3	n38	164	1	0	XC338	.	.	1	164	.	486	30	NONKEY ARC BASIC
484	d3	n38	155	1	0	XD338	.	.	0	0	.	487	31	NONKEY ARC BASIC
485	e3	n38	149	1	0	XE338	.	.	0	0	.	488	32	NONKEY ARC BASIC
486	f3	n38	152	1	0	XF338	.	.	0	0	.	489	33	NONKEY ARC BASIC
487	g3	n38	149	1	0	XG338	.	.	0	0	.	490	34	NONKEY ARC BASIC
488	h3	n38	150	1	0	XH338	.	.	0	0	.	491	35	NONKEY ARC BASIC
489	i3	n38	145	1	0	XI338	.	.	0	0	-41	492	36	LOWERBD NONBASIC
490	j3	n38	148	1	0	XJ338	.	.	0	0	-38	493	37	LOWERBD NONBASIC
491	k3	n38	169	1	0	XK338	.	.	0	0	.	494	38	NONKEY ARC BASIC
492	l3	n38	173	1	0	XL338	.	.	0	0	-100000012	495	39	LOWERBD NONBASIC
493	a3	n39	300	1	0	XA339	.	.	0	0	-112	496	28	LOWERBD NONBASIC
494	b3	n39	149	1	0	XB339	.	.	0	0	.	497	29	KEY_ARC BASIC
495	c3	n39	214	1	0	XC339	.	.	1	214	.	498	30	NONKEY ARC BASIC
496	d3	n39	180	1	0	XD339	.	.	0	0	.	499	31	NONKEY ARC BASIC
497	e3	n39	154	1	0	XE339	.	.	0	0	.	500	32	NONKEY ARC BASIC
498	f3	n39	167	1	0	XF339	.	.	0	0	.	501	33	NONKEY ARC BASIC
499	g3	n39	158	1	0	XG339	.	.	0	0	.	502	34	NONKEY ARC BASIC
500	h3	n39	159	1	0	XH339	.	.	0	0	-19	503	35	LOWERBD NONBASIC
501	i3	n39	147	1	0	XI339	.	.	0	0	-85	504	36	LOWERBD NONBASIC
502	j3	n39	149	1	0	XJ339	.	.	0	0	-83	505	37	LOWERBD NONBASIC
503	k3	n39	232	1	0	XK339	.	.	0	0	.	506	38	NONKEY ARC BASIC
504	l3	n39	250	1	0	XL339	.	.	0	0	-99999981	507	39	LOWERBD NONBASIC
505	a3	n40	300	1	0	XA340	.	.	0	0	.	508	28	KEY_ARC BASIC
506	b3	n40	191	1	0	XB340	.	.	0	0	-48	509	29	LOWERBD NONBASIC
507	c3	n40	300	1	0	XC340	.	.	1	300	.	510	30	NONKEY ARC BASIC
508	d3	n40	230	1	0	XD340	.	.	0	0	.	511	31	NONKEY ARC BASIC
509	e3	n40	180	1	0	XE340	.	.	0	0	-27	512	32	LOWERBD NONBASIC
510	f3	n40	215	1	0	XF340	.	.	0	0	.	513	33	NONKEY ARC BASIC
511	g3	n40	193	1	0	XG340	.	.	0	0	-16	514	34	LOWERBD NONBASIC
512	h3	n40	182	1	0	XH340	.	.	0	0	-33	515	35	LOWERBD NONBASIC
513	i3	n40	179	1	0	XI340	.	.	0	0	-90	516	36	LOWERBD NONBASIC
514	j3	n40	180	1	0	XJ340	.	.	0	0	-89	517	37	LOWERBD NONBASIC
515	k3	n40	290	1	0	XK340	.	.	0	0	.	518	38	NONKEY ARC BASIC
516	l3	n40	298	1	0	XL340	.	.	0	0	-99999970	519	39	LOWERBD NONBASIC
517	a3	n41	300	1	0	XA341	.	.	0	0	.	520	28	KEY_ARC BASIC
518	b3	n41	186	1	0	XB341	.	.	0	0	-111	521	29	LOWERBD NONBASIC
519	c3	n41	284	1	0	XC341	.	.	1	284	.	522	30	NONKEY ARC BASIC
520	d3	n41	234	1	0	XD341	.	.	0	0	.	523	31	NONKEY ARC BASIC
521	e3	n41	199	1	0	XE341	.	.	0	0	-66	524	32	LOWERBD NONBASIC
522	f3	n41	211	1	0	XF341	.	.	0	0	-45	525	33	LOWERBD NONBASIC
523	g3	n41	203	1	0	XG341	.	.	0	0	-64	526	34	LOWERBD NONBASIC
524	h3	n41	212	1	0	XH341	.	.	0	0	-61	527	35	LOWERBD NONBASIC
525	i3	n41	178	1	0	XI341	.	.	0	0	-149	528	36	LOWERBD NONBASIC
526	j3	n41	179	1	0	XJ341	.	.	0	0	-148	529	37	LOWERBD NONBASIC
527	k3	n41	296	1	0	XK341	.	.	0	0	-31	530	38	LOWERBD NONBASIC
528	l3	n41	298	1	0	XL341	.	.	0	0	-100000028	531	39	LOWERBD NONBASIC
529	a3	n42	300	1	0	XA342	.	.	0	0	.	532	28	KEY_ARC BASIC
530	b3	n42	144	1	0	XB342	.	.	0	0	.	533	29	NONKEY ARC BASIC
531	c3	n42	192	1	0	XC342	.	.	1	192	.	534	30	NONKEY ARC BASIC
532	d3	n42	168	1	0	XD342	.	.	0	0	.	535	31	NONKEY ARC BASIC
533	e3	n42	142	1	0	XE342	.	.	0	0	.	536	32	NONKEY ARC BASIC
534	f3	n42	153	1	0	XF342	.	.	0	0	-13	537	33	LOWERBD NONBASIC
535	g3	n42	144	1	0	XG342	.	.	0	0	.	538	34	NONKEY ARC BASIC
536	h3	n42	150	1	0	XH342	.	.	0	0	.	539	35	NONKEY ARC BASIC
537	i3	n42	133	1	0	XI342	.	.	0	0	-71	540	36	LOWERBD NONBASIC
538	j3	n42	133	1	0	XJ342	.	.	0	0	-71	541	37	LOWERBD NONBASIC
539	k3	n42	204	1	0	XK342	.	.	0	0	.	542	38	NONKEY ARC BASIC
540	l3	n42	228	1	0	XL342	.	.	0	0	-99999975	543	39	LOWERBD NONBASIC

OBS	_FROM_	_TO_	_COST_	_CAPAC_	_LO_	_NAME_	_SUPPLY_	_DEMAND_	_FLOW_	_FCOST_	_RCOST_	_ANUMB_	_TNUMB_	_STATUS_
541	a3	n43	300	1	0	XA343	.	.	0	0	.	544	28	KEY_ARC BASIC
542	b3	n43	158	1	0	XB343	.	.	0	0	.	545	29	NONKEY ARC BASIC
543	c3	n43	222	1	0	XC343	.	.	1	222	.	546	30	NONKEY ARC BASIC
544	d3	n43	189	1	0	XD343	.	.	0	0	.	547	31	NONKEY ARC BASIC
545	e3	n43	162	1	0	XE343	.	.	0	0	-58	548	32	LOWERBD NONBASIC
546	f3	n43	173	1	0	XF343	.	.	0	0	-38	549	33	LOWERBD NONBASIC
547	g3	n43	164	1	0	XG343	.	.	0	0	-58	550	34	LOWERBD NONBASIC
548	h3	n43	168	1	0	XH343	.	.	0	0	-60	551	35	LOWERBD NONBASIC
549	i3	n43	155	1	0	XI343	.	.	0	0	-127	552	36	LOWERBD NONBASIC
550	j3	n43	153	1	0	XJ343	.	.	0	0	-129	553	37	LOWERBD NONBASIC
551	k3	n43	251	1	0	XK343	.	.	0	0	-39	554	38	LOWERBD NONBASIC
552	l3	n43	300	1	0	XL343	.	.	0	0	-99999981	555	39	LOWERBD NONBASIC
553	a3	n44	300	1	0	XA344	.	.	0	0	.	556	28	KEY_ARC BASIC
554	b3	n44	182	1	0	XB344	.	.	0	0	-82	557	29	LOWERBD NONBASIC
555	c3	n44	290	1	0	XC344	.	.	1	290	.	558	30	NONKEY ARC BASIC
556	d3	n44	226	1	0	XD344	.	.	0	0	.	559	31	NONKEY ARC BASIC
557	e3	n44	188	1	0	XE344	.	.	0	0	-44	560	32	LOWERBD NONBASIC
558	f3	n44	206	1	0	XF344	.	.	0	0	.	561	33	NONKEY ARC BASIC
559	g3	n44	191	1	0	XG344	.	.	0	0	-43	562	34	LOWERBD NONBASIC
560	h3	n44	196	1	0	XH344	.	.	0	0	-44	563	35	LOWERBD NONBASIC
561	i3	n44	173	1	0	XI344	.	.	0	0	-121	564	36	LOWERBD NONBASIC
562	j3	n44	176	1	0	XJ344	.	.	0	0	-118	565	37	LOWERBD NONBASIC
563	k3	n44	294	1	0	XK344	.	.	0	0	.	566	38	NONKEY ARC BASIC
564	l3	n44	297	1	0	XL344	.	.	0	0	-99999996	567	39	LOWERBD NONBASIC
565	a3	n45	300	1	0	XA345	.	.	0	0	.	568	28	KEY_ARC BASIC
566	b3	n45	182	1	0	XB345	.	.	0	0	-107	569	29	LOWERBD NONBASIC
567	c3	n45	288	1	0	XC345	.	.	1	288	.	570	30	NONKEY ARC BASIC
568	d3	n45	226	1	0	XD345	.	.	0	0	.	571	31	NONKEY ARC BASIC
569	e3	n45	186	1	0	XE345	.	.	0	0	-71	572	32	LOWERBD NONBASIC
570	f3	n45	200	1	0	XF345	.	.	0	0	-48	573	33	LOWERBD NONBASIC
571	g3	n45	187	1	0	XG345	.	.	0	0	-72	574	34	LOWERBD NONBASIC
572	h3	n45	194	1	0	XH345	.	.	0	0	-71	575	35	LOWERBD NONBASIC
573	i3	n45	173	1	0	XI345	.	.	0	0	-146	576	36	LOWERBD NONBASIC
574	j3	n45	176	1	0	XJ345	.	.	0	0	-143	577	37	LOWERBD NONBASIC
575	k3	n45	292	1	0	XK345	.	.	0	0	-27	578	38	LOWERBD NONBASIC
576	l3	n45	297	1	0	XL345	.	.	0	0	-100000021	579	39	LOWERBD NONBASIC
577	a3	n46	300	1	0	XA346	.	.	0	0	.	580	28	KEY_ARC BASIC
578	b3	n46	164	1	0	XB346	.	.	0	0	-77	581	29	LOWERBD NONBASIC
579	c3	n46	236	1	0	XC346	.	.	1	236	.	582	30	NONKEY ARC BASIC
580	d3	n46	194	1	0	XD346	.	.	0	0	.	583	31	NONKEY ARC BASIC
581	e3	n46	167	1	0	XE346	.	.	0	0	-42	584	32	LOWERBD NONBASIC
582	f3	n46	182	1	0	XF346	.	.	0	0	-18	585	33	LOWERBD NONBASIC
583	g3	n46	168	1	0	XG346	.	.	0	0	-43	586	34	LOWERBD NONBASIC
584	h3	n46	174	1	0	XH346	.	.	0	0	-43	587	35	LOWERBD NONBASIC
585	i3	n46	158	1	0	XI346	.	.	0	0	-113	588	36	LOWERBD NONBASIC
586	j3	n46	160	1	0	XJ346	.	.	0	0	-111	589	37	LOWERBD NONBASIC
587	k3	n46	271	1	0	XK346	.	.	0	0	.	590	38	NONKEY ARC BASIC
588	l3	n46	299	1	0	XL346	.	.	0	0	-99999971	591	39	LOWERBD NONBASIC
589	a3	n47	300	1	0	XA347	.	.	0	0	.	592	28	KEY_ARC BASIC
590	b3	n47	149	1	0	XB347	.	.	0	0	-109	593	29	LOWERBD NONBASIC
591	c3	n47	199	1	0	XC347	.	.	1	199	.	594	30	NONKEY ARC BASIC
592	d3	n47	172	1	0	XD347	.	.	0	0	.	595	31	NONKEY ARC BASIC
593	e3	n47	148	1	0	XE347	.	.	0	0	-55	596	32	LOWERBD NONBASIC
594	f3	n47	161	1	0	XF347	.	.	0	0	-33	597	33	LOWERBD NONBASIC
595	g3	n47	149	1	0	XG347	.	.	0	0	-56	598	34	LOWERBD NONBASIC
596	h3	n47	154	1	0	XH347	.	.	0	0	-57	599	35	LOWERBD NONBASIC
597	i3	n47	141	1	0	XI347	.	.	0	0	-124	600	36	LOWERBD NONBASIC
598	j3	n47	144	1	0	XJ347	.	.	0	0	-121	601	37	LOWERBD NONBASIC
599	k3	n47	215	1	0	XK347	.	.	0	0	-50	602	38	LOWERBD NONBASIC
600	l3	n47	230	1	0	XL347	.	.	0	0	-100000034	603	39	LOWERBD NONBASIC

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601	a3	n48	165	1	0	XA348	.	.	0	0	.	604	28	KEY_ARC BASIC
602	b3	n48	159	1	0	XB348	.	.	0	0	.	605	29	NONKEY ARC BASIC
603	c3	n48	165	1	0	XC348	.	.	1	165	.	606	30	NONKEY ARC BASIC
604	d3	n48	165	1	0	XD348	.	.	0	0	.	607	31	NONKEY ARC BASIC
605	e3	n48	155	1	0	XE348	.	.	0	0	-1.00	608	32	LOWERBD NONBASIC
606	f3	n48	163	1	0	XF348	.	.	0	0	-43.00	609	33	LOWERBD NONBASIC
607	g3	n48	158	1	0	XG348	.	.	0	0	.	610	34	NONKEY ARC BASIC
608	h3	n48	162	1	0	XH348	.	.	0	0	-2.00	611	35	LOWERBD NONBASIC
609	i3	n48	147	1	0	XI348	.	.	0	0	-71.00	612	36	LOWERBD NONBASIC
610	j3	n48	155	1	0	XJ348	.	.	0	0	-63.00	613	37	LOWERBD NONBASIC
611	k3	n48	165	1	0	XK348	.	.	0	0	-53.00	614	38	LOWERBD NONBASIC
612	l3	n48	165	1	0	XL348	.	.	0	0	-100000052.00	615	39	LOWERBD NONBASIC
613	t	s1	0	99999999	0	XTS1	.	.	16	0	.	1	88	KEY_ARC BASIC
614	t	s2	0	99999999	0	XTS2	.	.	16	0	.	14	88	KEY_ARC BASIC
615	t	s3	0	99999999	0	XTS3	.	.	16	0	.	27	88	KEY_ARC BASIC
616	n01	t	0	1	0	X01T	.	D	1	0	298.75	616	40	UPPERBD NONBASIC
617	n02	t	0	1	0	X02T	.	D	1	0	194.75	617	41	UPPERBD NONBASIC
618	n03	t	0	1	0	X03T	.	D	1	0	186.75	618	42	UPPERBD NONBASIC
619	n04	t	0	1	0	X04T	.	D	1	0	209.75	619	43	UPPERBD NONBASIC
620	n05	t	0	1	0	X05T	.	D	1	0	283.75	620	44	UPPERBD NONBASIC
621	n06	t	0	1	0	X06T	.	D	1	0	285.75	621	45	UPPERBD NONBASIC
622	n07	t	0	1	0	X07T	.	D	1	0	313.75	622	46	UPPERBD NONBASIC
623	n08	t	0	1	0	X08T	.	D	1	0	320.75	623	47	UPPERBD NONBASIC
624	n09	t	0	1	0	X09T	.	D	1	0	307.75	624	48	UPPERBD NONBASIC
625	n10	t	0	1	0	X10T	.	D	1	0	284.75	625	49	UPPERBD NONBASIC
626	n11	t	0	1	0	X11T	.	D	1	0	307.75	626	50	UPPERBD NONBASIC
627	n12	t	0	1	0	X12T	.	D	1	0	315.75	627	51	UPPERBD NONBASIC
628	n13	t	0	1	0	X13T	.	D	1	0	303.75	628	52	UPPERBD NONBASIC
629	n14	t	0	1	0	X14T	.	D	1	0	294.75	629	53	UPPERBD NONBASIC
630	n15	t	0	1	0	X15T	.	D	1	0	319.75	630	54	UPPERBD NONBASIC
631	n16	t	0	1	0	X16T	.	D	1	0	336.75	631	55	UPPERBD NONBASIC
632	n17	t	0	1	0	X17T	.	D	1	0	84.00	632	56	UPPERBD NONBASIC
633	n18	t	0	1	0	X18T	.	D	1	0	103.00	633	57	UPPERBD NONBASIC
634	n19	t	0	1	0	X19T	.	D	1	0	113.00	634	58	UPPERBD NONBASIC
635	n20	t	0	1	0	X20T	.	D	1	0	.	635	59	NONKEY ARC BASIC
636	n21	t	0	1	0	X21T	.	D	1	0	169.00	636	60	UPPERBD NONBASIC
637	n22	t	0	1	0	X22T	.	D	1	0	142.00	637	61	UPPERBD NONBASIC
638	n23	t	0	1	0	X23T	.	D	1	0	165.00	638	62	UPPERBD NONBASIC
639	n24	t	0	1	0	X24T	.	D	1	0	167.00	639	63	UPPERBD NONBASIC
640	n25	t	0	1	0	X25T	.	D	1	0	117.00	640	64	UPPERBD NONBASIC
641	n26	t	0	1	0	X26T	.	D	1	0	110.00	641	65	UPPERBD NONBASIC
642	n27	t	0	1	0	X27T	.	D	1	0	78.00	642	66	UPPERBD NONBASIC
643	n28	t	0	1	0	X28T	.	D	1	0	201.00	643	67	UPPERBD NONBASIC
644	n29	t	0	1	0	X29T	.	D	1	0	112.00	644	68	UPPERBD NONBASIC
645	n30	t	0	1	0	X30T	.	D	1	0	112.00	645	69	UPPERBD NONBASIC
646	n31	t	0	1	0	X31T	.	D	1	0	110.00	646	70	UPPERBD NONBASIC
647	n32	t	0	1	0	X32T	.	D	1	0	112.00	647	71	UPPERBD NONBASIC
648	n33	t	0	1	0	X33T	.	D	1	0	88.00	648	72	UPPERBD NONBASIC
649	n34	t	0	1	0	X34T	.	D	1	0	.	649	73	NONKEY ARC BASIC
650	n35	t	0	1	0	X35T	.	D	1	0	3.00	650	74	UPPERBD NONBASIC
651	n36	t	0	1	0	X36T	.	D	1	0	32.00	651	75	UPPERBD NONBASIC
652	n37	t	0	1	0	X37T	.	D	1	0	208.00	652	76	UPPERBD NONBASIC
653	n38	t	0	1	0	X38T	.	D	1	0	126.00	653	77	UPPERBD NONBASIC

OBS	_FROM_	_TO_	_COST_	_CAPAC_	_LO_	_NAME_	_SUPPLY_	_DEMAND_	_FLOW_	_FCOST_	_RCOST_	_ANUMB_	_TNUMB_	_STATUS_
654	n39	t	0	1	0	X39T	.	D	1	0	172	654	78	UPPERBD NONBASIC
655	n40	t	0	1	0	X40T	.	D	1	0	209	655	79	UPPERBD NONBASIC
656	n41	t	0	1	0	X41T	.	D	1	0	267	656	80	UPPERBD NONBASIC
657	n42	t	0	1	0	X42T	.	D	1	0	144	657	81	UPPERBD NONBASIC
658	n43	t	0	1	0	X43T	.	D	1	0	222	658	82	UPPERBD NONBASIC
659	n44	t	0	1	0	X44T	.	D	1	0	234	659	83	UPPERBD NONBASIC
660	n45	t	0	1	0	X45T	.	D	1	0	259	660	84	UPPERBD NONBASIC
661	n46	t	0	1	0	X46T	.	D	1	0	211	661	85	UPPERBD NONBASIC
662	n47	t	0	1	0	X47T	.	D	1	0	205	662	86	UPPERBD NONBASIC
663	n48	t	0	1	0	X48T	.	D	1	0	158	663	87	UPPERBD NONBASIC
664			0	99999999	0	XS1A2	.	.	0	0	.	0	.	NONKEY BASIC
										========				
										9917				

W.3 Solution for $p = 2$

OBS	_FROM_	_TO_	_COST_	_CAPAC_	_LO_	_NAME_	_SUPPLY_	_DEMAND_	_FLOW_	_FCOST_	_RCOST_	_ANUMB_	_TNUMB_	_STATUS_
1	s1	a1	0	16	0	XS1A1	.	.	0	0	.	2	1	KEY_ARC BASIC
2	s2	a2	0	16	0	XS2A2	.	.	0	0	.	15	14	KEY_ARC BASIC
3	s3	a3	0	16	0	XS3A3	.	.	0	0	.	28	27	KEY_ARC BASIC
4	s1	b1	0	16	0	XS1B1	.	.	0	0	.	3	1	KEY_ARC BASIC
5	s2	b2	0	16	0	XS2B2	.	.	0	0	.	16	14	KEY_ARC BASIC
6	s3	b3	0	16	0	XS3B3	.	.	0	0	.	29	27	KEY_ARC BASIC
7	s1	c1	0	16	0	XS1C1	.	.	16	0	.	4	1	KEY_ARC BASIC
8	s2	c2	0	16	0	XS2C2	.	.	16	0	.	17	14	KEY_ARC BASIC
9	s3	c3	0	16	0	XS3C3	.	.	16	0	.	30	27	KEY_ARC BASIC
10	s1	d1	0	16	0	XS1D1	.	.	0	0	.	5	1	KEY_ARC BASIC
11	s2	d2	0	16	0	XS2D2	.	.	0	0	.	18	14	KEY_ARC BASIC
12	s3	d3	0	16	0	XS3D3	.	.	0	0	.	31	27	KEY_ARC BASIC
13	s1	e1	0	16	0	XS1E1	.	.	0	0	.	6	1	KEY_ARC BASIC
14	s2	e2	0	16	0	XS2E2	.	.	0	0	.	19	14	KEY_ARC BASIC
15	s3	e3	0	16	0	XS3E3	.	.	0	0	.	32	27	KEY_ARC BASIC
16	s1	f1	0	16	0	XS1F1	.	.	0	0	.	7	1	KEY_ARC BASIC
17	s2	f2	0	16	0	XS2F2	.	.	0	0	.	20	14	KEY_ARC BASIC
18	s3	f3	0	16	0	XS3F3	.	.	0	0	.	33	27	KEY_ARC BASIC
19	s1	g1	0	16	0	XS1G1	.	.	0	0	.	8	1	KEY_ARC BASIC
20	s2	g2	0	16	0	XS2G2	.	.	0	0	.	21	14	KEY_ARC BASIC
21	s3	g3	0	16	0	XS3G3	.	.	0	0	.	34	27	KEY_ARC BASIC
22	s1	h1	0	16	0	XS1H1	.	.	0	0	.	9	1	KEY_ARC BASIC
23	s2	h2	0	16	0	XS2H2	.	.	0	0	.	22	14	KEY_ARC BASIC
24	s3	h3	0	16	0	XS3H3	.	.	0	0	.	35	27	KEY_ARC BASIC
25	s1	i1	0	16	0	XS1I1	.	.	0	0	.	10	1	KEY_ARC BASIC
26	s2	i2	0	16	0	XS2I2	.	.	0	0	.	23	14	KEY_ARC BASIC
27	s3	i3	0	16	0	XS3I3	.	.	0	0	.	36	27	KEY_ARC BASIC
28	s1	j1	0	16	0	XS1J1	.	.	0	0	.	11	1	KEY_ARC BASIC
29	s2	j2	0	16	0	XS2J2	.	.	0	0	.	24	14	KEY_ARC BASIC
30	s3	j3	0	16	0	XS3J3	.	.	0	0	.	37	27	KEY_ARC BASIC
31	s1	k1	0	16	0	XS1K1	.	.	0	0	.	12	1	KEY_ARC BASIC
32	s2	k2	0	16	0	XS2K2	.	.	0	0	.	25	14	KEY_ARC BASIC
33	s3	k3	0	16	0	XS3K3	.	.	0	0	.	38	27	KEY_ARC BASIC
34	s1	l1	0	16	0	XS1L1	.	.	16	0	.	13	1	KEY_ARC BASIC
35	s2	l2	0	16	0	XS2L2	.	.	16	0	.	26	14	KEY_ARC BASIC
36	s3	l3	0	16	0	XS3L3	.	.	16	0	.	39	27	KEY_ARC BASIC
37	a1	n01	0	1	0	XA101	.	.	0	0	-100000091	40	2	LOWERBD NONBASIC
38	b1	n01	160	1	0	XB101	.	.	0	0	.	41	3	KEY_ARC BASIC
39	c1	n01	108	1	0	XC101	.	.	1	108	.	42	4	NONKEY ARC BASIC
40	d1	n01	134	1	0	XD101	.	.	0	0	.	43	5	NONKEY ARC BASIC
41	e1	n01	157	1	0	XE101	.	.	0	0	.	44	6	NONKEY ARC BASIC
42	f1	n01	148	1	0	XF101	.	.	0	0	.	45	7	NONKEY ARC BASIC
43	g1	n01	157	1	0	XG101	.	.	0	0	.	46	8	NONKEY ARC BASIC
44	h1	n01	155	1	0	XH101	.	.	0	0	.	47	9	NONKEY ARC BASIC
45	i1	n01	167	1	0	XI101	.	.	0	0	.	48	10	NONKEY ARC BASIC
46	j1	n01	165	1	0	XJ101	.	.	0	0	.	49	11	NONKEY ARC BASIC
47	k1	n01	90	1	0	XK101	.	.	0	0	.	50	12	NONKEY ARC BASIC
48	l1	n01	70	1	0	XL101	.	.	1	70	.	51	13	NONKEY ARC BASIC
49	a1	n02	60	1	0	XA102	.	.	0	0	.	52	2	NONKEY ARC BASIC
50	b1	n02	60	1	0	XB102	.	.	0	0	.	53	3	NONKEY ARC BASIC
51	c1	n02	60	1	0	XC102	.	.	1	60	.	54	4	KEY_ARC BASIC
52	d1	n02	60	1	0	XD102	.	.	0	0	.	55	5	NONKEY ARC BASIC
53	e1	n02	60	1	0	XE102	.	.	0	0	.	56	6	NONKEY ARC BASIC
54	f1	n02	60	1	0	XF102	.	.	0	0	.	57	7	NONKEY ARC BASIC
55	g1	n02	60	1	0	XG102	.	.	0	0	.	58	8	NONKEY ARC BASIC
56	h1	n02	60	1	0	XH102	.	.	0	0	.	59	9	NONKEY ARC BASIC
57	i1	n02	60	1	0	XI102	.	.	0	0	.	60	10	NONKEY ARC BASIC
58	j1	n02	60	1	0	XJ102	.	.	0	0	.	61	11	NONKEY ARC BASIC
59	k1	n02	60	1	0	XK102	.	.	0	0	.	62	12	NONKEY ARC BASIC

60	11	n02	60	1	0	XL102	.	.	1	60	.	63	13	MONKEY ARC BASIC

OBS	_FROM_	_TO_	_COST_	_CAPAC_	_LO_	_NAME_	_SUPPLY_	_DEMAND_	_FLOW_	_FCOST_	_RCOST_	_ANUMB_	_TNUMB_	_STATUS_
61	a1	n03	60	1	0	XA103	.	.	0	0	.	64	2	NONKEY ARC BASIC
62	b1	n03	49	1	0	XB103	.	.	0	0	.	65	3	NONKEY ARC BASIC
63	c1	n03	60	1	0	XC103	.	.	1	60	.	66	4	NONKEY ARC BASIC
64	d1	n03	60	1	0	XD103	.	.	0	0	.	67	5	KEY_ARC BASIC
65	e1	n03	42	1	0	XE103	.	.	0	0	.	68	6	NONKEY ARC BASIC
66	f1	n03	60	1	0	XF103	.	.	0	0	.	69	7	NONKEY ARC BASIC
67	g1	n03	59	1	0	XG103	.	.	0	0	.	70	8	NONKEY ARC BASIC
68	h1	n03	60	1	0	XH103	.	.	0	0	.	71	9	NONKEY ARC BASIC
69	i1	n03	51	1	0	XI103	.	.	0	0	.	72	10	NONKEY ARC BASIC
70	j1	n03	45	1	0	XJ103	.	.	0	0	.	73	11	NONKEY ARC BASIC
71	k1	n03	60	1	0	XK103	.	.	0	0	.	74	12	NONKEY ARC BASIC
72	l1	n03	60	1	0	XL103	.	.	1	60	.	75	13	NONKEY ARC BASIC
73	a1	n04	32	1	0	XA104	.	.	0	0	.	76	2	NONKEY ARC BASIC
74	b1	n04	60	1	0	XB104	.	.	0	0	.	77	3	NONKEY ARC BASIC
75	c1	n04	60	1	0	XC104	.	.	1	60	.	78	4	NONKEY ARC BASIC
76	d1	n04	60	1	0	XD104	.	.	0	0	.	79	5	NONKEY ARC BASIC
77	e1	n04	60	1	0	XE104	.	.	0	0	.	80	6	NONKEY ARC BASIC
78	f1	n04	90	1	0	XF104	.	.	0	0	.	81	7	NONKEY ARC BASIC
79	g1	n04	90	1	0	XG104	.	.	0	0	.	82	8	NONKEY ARC BASIC
80	h1	n04	90	1	0	XH104	.	.	0	0	.	83	9	KEY_ARC BASIC
81	i1	n04	88	1	0	XI104	.	.	0	0	.	84	10	NONKEY ARC BASIC
82	j1	n04	60	1	0	XJ104	.	.	0	0	.	85	11	NONKEY ARC BASIC
83	k1	n04	60	1	0	XK104	.	.	0	0	.	86	12	NONKEY ARC BASIC
84	l1	n04	60	1	0	XL104	.	.	1	60	.	87	13	NONKEY ARC BASIC
85	a1	n05	264	1	0	XA105	.	.	0	0	.	88	2	NONKEY ARC BASIC
86	b1	n05	156	1	0	XB105	.	.	0	0	.	89	3	NONKEY ARC BASIC
87	c1	n05	242	1	0	XC105	.	.	1	242	.	90	4	NONKEY ARC BASIC
88	d1	n05	203	1	0	XD105	.	.	0	0	.	91	5	NONKEY ARC BASIC
89	e1	n05	162	1	0	XE105	.	.	0	0	.	92	6	NONKEY ARC BASIC
90	f1	n05	178	1	0	XF105	.	.	0	0	.	93	7	NONKEY ARC BASIC
91	g1	n05	162	1	0	XG105	.	.	0	0	.	94	8	NONKEY ARC BASIC
92	h1	n05	169	1	0	XH105	.	.	0	0	.	95	9	NONKEY ARC BASIC
93	i1	n05	150	1	0	XI105	.	.	0	0	.	96	10	NONKEY ARC BASIC
94	j1	n05	150	1	0	XJ105	.	.	0	0	.	97	11	NONKEY ARC BASIC
95	k1	n05	238	1	0	XK105	.	.	0	0	.	98	12	NONKEY ARC BASIC
96	l1	n05	241	1	0	XL105	.	.	1	241	.	99	13	KEY_ARC BASIC
97	a1	n06	300	1	0	XA106	.	.	0	0	.	100	2	NONKEY ARC BASIC
98	b1	n06	157	1	0	XB106	.	.	0	0	.	101	3	NONKEY ARC BASIC
99	c1	n06	218	1	0	XC106	.	.	1	218	.	102	4	NONKEY ARC BASIC
100	d1	n06	185	1	0	XD106	.	.	0	0	.	103	5	NONKEY ARC BASIC
101	e1	n06	155	1	0	XE106	.	.	0	0	.	104	6	NONKEY ARC BASIC
102	f1	n06	171	1	0	XF106	.	.	0	0	.	105	7	NONKEY ARC BASIC
103	g1	n06	160	1	0	XG106	.	.	0	0	.	106	8	NONKEY ARC BASIC
104	h1	n06	165	1	0	XH106	.	.	0	0	.	107	9	NONKEY ARC BASIC
105	i1	n06	149	1	0	XI106	.	.	0	0	.	108	10	NONKEY ARC BASIC
106	j1	n06	152	1	0	XJ106	.	.	0	0	.	109	11	NONKEY ARC BASIC
107	k1	n06	239	1	0	XK106	.	.	0	0	.	110	12	NONKEY ARC BASIC
108	l1	n06	287	1	0	XL106	.	.	1	287	.	111	13	KEY_ARC BASIC
109	a1	n07	300	1	0	XA107	.	.	0	0	.	112	2	NONKEY ARC BASIC
110	b1	n07	188	1	0	XB107	.	.	0	0	.	113	3	NONKEY ARC BASIC
111	c1	n07	292	1	0	XC107	.	.	1	292	.	114	4	KEY_ARC BASIC
112	d1	n07	229	1	0	XD107	.	.	0	0	.	115	5	NONKEY ARC BASIC
113	e1	n07	189	1	0	XE107	.	.	0	0	.	116	6	NONKEY ARC BASIC
114	f1	n07	202	1	0	XF107	.	.	0	0	.	117	7	NONKEY ARC BASIC
115	g1	n07	192	1	0	XG107	.	.	0	0	.	118	8	NONKEY ARC BASIC
116	h1	n07	196	1	0	XH107	.	.	0	0	.	119	9	NONKEY ARC BASIC
117	i1	n07	175	1	0	XI107	.	.	0	0	.	120	10	NONKEY ARC BASIC
118	j1	n07	180	1	0	XJ107	.	.	0	0	.	121	11	NONKEY ARC BASIC
119	k1	n07	292	1	0	XK107	.	.	0	0	.	122	12	NONKEY ARC BASIC
120	l1	n07	300	1	0	XL107	.	.	1	300	.	123	13	NONKEY ARC BASIC

OBS	_FROM_	_TO_	_COST_	_CAPAC_	_LO_	_NAME_	_SUPPLY_	_DEMAND_	_FLOW_	_FCOST_	_RCOST_	_ANUMB_	_TNUMB_	_STATUS_
121	a1	n08	300	1	0	XA108	.	.	0	0	.	124	2	NONKEY ARC BASIC
122	b1	n08	190	1	0	XB108	.	.	0	0	.	125	3	NONKEY ARC BASIC
123	c1	n08	272	1	0	XC108	.	.	1	272	.	126	4	NONKEY ARC BASIC
124	d1	n08	228	1	0	XD108	.	.	0	0	.	127	5	NONKEY ARC BASIC
125	e1	n08	193	1	0	XE108	.	.	0	0	.	128	6	NONKEY ARC BASIC
126	f1	n08	209	1	0	XF108	.	.	0	0	.	129	7	NONKEY ARC BASIC
127	g1	n08	195	1	0	XG108	.	.	0	0	.	130	8	NONKEY ARC BASIC
128	h1	n08	202	1	0	XH108	.	.	0	0	.	131	9	NONKEY ARC BASIC
129	i1	n08	183	1	0	XI108	.	.	0	0	.	132	10	NONKEY ARC BASIC
130	j1	n08	187	1	0	XJ108	.	.	0	0	.	133	11	NONKEY ARC BASIC
131	k1	n08	300	1	0	XK108	.	.	0	0	.	134	12	NONKEY ARC BASIC
132	l1	n08	300	1	0	XL108	.	.	1	300	.	135	13	KEY_ARC BASIC
133	a1	n09	300	1	0	XA109	.	.	0	0	.	136	2	NONKEY ARC BASIC
134	b1	n09	156	1	0	XB109	.	.	0	0	.	137	3	NONKEY ARC BASIC
135	c1	n09	213	1	0	XC109	.	.	1	213	.	138	4	NONKEY ARC BASIC
136	d1	n09	179	1	0	XD109	.	.	0	0	.	139	5	NONKEY ARC BASIC
137	e1	n09	158	1	0	XE109	.	.	0	0	.	140	6	KEY_ARC BASIC
138	f1	n09	169	1	0	XF109	.	.	0	0	.	141	7	NONKEY ARC BASIC
139	g1	n09	159	1	0	XG109	.	.	0	0	.	142	8	NONKEY ARC BASIC
140	h1	n09	159	1	0	XH109	.	.	0	0	.	143	9	NONKEY ARC BASIC
141	i1	n09	150	1	0	XI109	.	.	0	0	.	144	10	NONKEY ARC BASIC
142	j1	n09	142	1	0	XJ109	.	.	0	0	.	145	11	NONKEY ARC BASIC
143	k1	n09	227	1	0	XK109	.	.	0	0	.	146	12	NONKEY ARC BASIC
144	l1	n09	261	1	0	XL109	.	.	1	261	.	147	13	NONKEY ARC BASIC
145	a1	n10	300	1	0	XA110	.	.	0	0	.	148	2	NONKEY ARC BASIC
146	b1	n10	156	1	0	XB110	.	.	0	0	.	149	3	NONKEY ARC BASIC
147	c1	n10	217	1	0	XC110	.	.	1	217	.	150	4	NONKEY ARC BASIC
148	d1	n10	184	1	0	XD110	.	.	0	0	-1127	151	5	LOWERBD NONBASIC
149	e1	n10	158	1	0	XE110	.	.	0	0	.	152	6	NONKEY ARC BASIC
150	f1	n10	171	1	0	XF110	.	.	0	0	.	153	7	NONKEY ARC BASIC
151	g1	n10	158	1	0	XG110	.	.	0	0	.	154	8	NONKEY ARC BASIC
152	h1	n10	163	1	0	XH110	.	.	0	0	.	155	9	NONKEY ARC BASIC
153	i1	n10	149	1	0	XI110	.	.	0	0	.	156	10	NONKEY ARC BASIC
154	j1	n10	151	1	0	XJ110	.	.	0	0	.	157	11	NONKEY ARC BASIC
155	k1	n10	241	1	0	XK110	.	.	0	0	.	158	12	KEY_ARC BASIC
156	l1	n10	288	1	0	XL110	.	.	1	288	.	159	13	NONKEY ARC BASIC
157	a1	n11	300	1	0	XA111	.	.	0	0	.	160	2	NONKEY ARC BASIC
158	b1	n11	180	1	0	XB111	.	.	0	0	.	161	3	NONKEY ARC BASIC
159	c1	n11	295	1	0	XC111	.	.	1	295	.	162	4	NONKEY ARC BASIC
160	d1	n11	237	1	0	XD111	.	.	0	0	.	163	5	NONKEY ARC BASIC
161	e1	n11	180	1	0	XE111	.	.	0	0	.	164	6	NONKEY ARC BASIC
162	f1	n11	189	1	0	XF111	.	.	0	0	.	165	7	NONKEY ARC BASIC
163	g1	n11	180	1	0	XG111	.	.	0	0	.	166	8	NONKEY ARC BASIC
164	h1	n11	180	1	0	XH111	.	.	0	0	.	167	9	NONKEY ARC BASIC
165	i1	n11	180	1	0	XI111	.	.	0	0	.	168	10	NONKEY ARC BASIC
166	j1	n11	168	1	0	XJ111	.	.	0	0	.	169	11	NONKEY ARC BASIC
167	k1	n11	300	1	0	XK111	.	.	0	0	-1399999672	170	12	LOWERBD NONBASIC
168	l1	n11	300	1	0	XL111	.	.	1	300	.	171	13	KEY_ARC BASIC
169	a1	n12	300	1	0	XA112	.	.	0	0	.	172	2	NONKEY ARC BASIC
170	b1	n12	188	1	0	XB112	.	.	0	0	.	173	3	KEY_ARC BASIC
171	c1	n12	289	1	0	XC112	.	.	1	289	.	174	4	NONKEY ARC BASIC
172	d1	n12	235	1	0	XD112	.	.	0	0	.	175	5	NONKEY ARC BASIC
173	e1	n12	198	1	0	XE112	.	.	0	0	.	176	6	NONKEY ARC BASIC
174	f1	n12	212	1	0	XF112	.	.	0	0	.	177	7	NONKEY ARC BASIC
175	g1	n12	200	1	0	XG112	.	.	0	0	.	178	8	NONKEY ARC BASIC
176	h1	n12	208	1	0	XH112	.	.	0	0	.	179	9	NONKEY ARC BASIC
177	i1	n12	181	1	0	XI112	.	.	0	0	.	180	10	NONKEY ARC BASIC
178	j1	n12	182	1	0	XJ112	.	.	0	0	.	181	11	NONKEY ARC BASIC
179	k1	n12	295	1	0	XK112	.	.	0	0	.	182	12	NONKEY ARC BASIC
180	l1	n12	300	1	0	XL112	.	.	1	300	.	183	13	NONKEY ARC BASIC

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181	a1	n13	300	1	0	XA113	.	.	0	0	.	184	2	NONKEY ARC BASIC
182	b1	n13	191	1	0	XB113	.	.	0	0	.	185	3	NONKEY ARC BASIC
183	c1	n13	291	1	0	XC113	.	.	1	291	.	186	4	NONKEY ARC BASIC
184	d1	n13	238	1	0	XD113	.	.	0	0	.	187	5	NONKEY ARC BASIC
185	e1	n13	191	1	0	XE113	.	.	0	0	.	188	6	NONKEY ARC BASIC
186	f1	n13	209	1	0	XF113	.	.	0	0	.	189	7	NONKEY ARC BASIC
187	g1	n13	193	1	0	XG113	.	.	0	0	.	190	8	NONKEY ARC BASIC
188	h1	n13	199	1	0	XH113	.	.	0	0	.	191	9	NONKEY ARC BASIC
189	i1	n13	180	1	0	XI113	.	.	0	0	.	192	10	NONKEY ARC BASIC
190	j1	n13	184	1	0	XJ113	.	.	0	0	.	193	11	NONKEY ARC BASIC
191	k1	n13	293	1	0	XK113	.	.	0	0	.	194	12	KEY_ARC BASIC
192	l1	n13	299	1	0	XL113	.	.	1	299	.	195	13	NONKEY ARC BASIC
193	a1	n14	300	1	0	XA114	.	.	0	0	.	196	2	NONKEY ARC BASIC
194	b1	n14	180	1	0	XB114	.	.	0	0	.	197	3	NONKEY ARC BASIC
195	c1	n14	293	1	0	XC114	.	.	1	293	.	198	4	NONKEY ARC BASIC
196	d1	n14	220	1	0	XD114	.	.	0	0	.	199	5	NONKEY ARC BASIC
197	e1	n14	184	1	0	XE114	.	.	0	0	.	200	6	NONKEY ARC BASIC
198	f1	n14	200	1	0	XF114	.	.	0	0	.	201	7	NONKEY ARC BASIC
199	g1	n14	188	1	0	XG114	.	.	0	0	.	202	8	NONKEY ARC BASIC
200	h1	n14	193	1	0	XH114	.	.	0	0	.	203	9	NONKEY ARC BASIC
201	i1	n14	173	1	0	XI114	.	.	0	0	.	204	10	NONKEY ARC BASIC
202	j1	n14	175	1	0	XJ114	.	.	0	0	.	205	11	NONKEY ARC BASIC
203	k1	n14	298	1	0	XK114	.	.	0	0	.	206	12	KEY_ARC BASIC
204	l1	n14	300	1	0	XL114	.	.	1	300	513	207	13	UPPERBD NONBASIC
205	a1	n15	300	1	0	XA115	.	.	0	0	.	208	2	NONKEY ARC BASIC
206	b1	n15	184	1	0	XB115	.	.	0	0	.	209	3	NONKEY ARC BASIC
207	c1	n15	290	1	0	XC115	.	.	1	290	.	210	4	NONKEY ARC BASIC
208	d1	n15	224	1	0	XD115	.	.	0	0	.	211	5	NONKEY ARC BASIC
209	e1	n15	186	1	0	XE115	.	.	0	0	.	212	6	NONKEY ARC BASIC
210	f1	n15	202	1	0	XF115	.	.	0	0	.	213	7	NONKEY ARC BASIC
211	g1	n15	188	1	0	XG115	.	.	0	0	.	214	8	KEY_ARC BASIC
212	h1	n15	192	1	0	XH115	.	.	0	0	.	215	9	NONKEY ARC BASIC
213	i1	n15	174	1	0	XI115	.	.	0	0	.	216	10	NONKEY ARC BASIC
214	j1	n15	176	1	0	XJ115	.	.	0	0	.	217	11	NONKEY ARC BASIC
215	k1	n15	294	1	0	XK115	.	.	0	0	.	218	12	NONKEY ARC BASIC
216	l1	n15	298	1	0	XL115	.	.	1	298	.	219	13	NONKEY ARC BASIC
217	a1	n16	300	1	0	XA116	.	.	0	0	.	220	2	NONKEY ARC BASIC
218	b1	n16	180	1	0	XB116	.	.	0	0	.	221	3	NONKEY ARC BASIC
219	c1	n16	292	1	0	XC116	.	.	1	292	.	222	4	NONKEY ARC BASIC
220	d1	n16	219	1	0	XD116	.	.	0	0	.	223	5	NONKEY ARC BASIC
221	e1	n16	183	1	0	XE116	.	.	0	0	.	224	6	NONKEY ARC BASIC
222	f1	n16	199	1	0	XF116	.	.	0	0	.	225	7	NONKEY ARC BASIC
223	g1	n16	186	1	0	XG116	.	.	0	0	.	226	8	NONKEY ARC BASIC
224	h1	n16	190	1	0	XH116	.	.	0	0	.	227	9	NONKEY ARC BASIC
225	i1	n16	171	1	0	XI116	.	.	0	0	.	228	10	NONKEY ARC BASIC
226	j1	n16	173	1	0	XJ116	.	.	0	0	.	229	11	NONKEY ARC BASIC
227	k1	n16	294	1	0	XK116	.	.	0	0	.	230	12	KEY_ARC BASIC
228	l1	n16	299	1	0	XL116	.	.	1	299	.	231	13	NONKEY ARC BASIC
229	a2	n17	0	1	0	XA217	.	.	0	0	.	232	15	NONKEY ARC BASIC
230	b2	n17	146	1	0	XB217	.	.	0	0	.	233	16	KEY_ARC BASIC
231	c2	n17	73	1	0	XC217	.	.	1	73	.	234	17	NONKEY ARC BASIC
232	d2	n17	112	1	0	XD217	.	.	0	0	.	235	18	NONKEY ARC BASIC
233	e2	n17	144	1	0	XE217	.	.	0	0	.	236	19	NONKEY ARC BASIC
234	f2	n17	129	1	0	XF217	.	.	0	0	-1602	237	20	LOWERBD NONBASIC
235	g2	n17	140	1	0	XG217	.	.	0	0	.	238	21	NONKEY ARC BASIC
236	h2	n17	135	1	0	XH217	.	.	0	0	.	239	22	NONKEY ARC BASIC
237	i2	n17	154	1	0	XI217	.	.	0	0	.	240	23	NONKEY ARC BASIC
238	j2	n17	152	1	0	XJ217	.	.	0	0	.	241	24	NONKEY ARC BASIC
239	k2	n17	38	1	0	XK217	.	.	0	0	.	242	25	NONKEY ARC BASIC
240	l2	n17	0	1	0	XL217	.	.	1	0	.	243	26	NONKEY ARC BASIC

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241	a2	n18	0	1	0	XA218	.	.	0.00000	0.000	.	244	15	NONKEY ARC BASIC
242	b2	n18	168	1	0	XB218	.	.	0.00000	0.000	.	245	16	NONKEY ARC BASIC
243	c2	n18	122	1	0	XC218	.	.	1.00000	122.000	.	246	17	NONKEY ARC BASIC
244	d2	n18	145	1	0	XD218	.	.	0.00000	0.000	.	247	18	NONKEY ARC BASIC
245	e2	n18	169	1	0	XE218	.	.	0.00000	0.000	.	248	19	KEY_ARC BASIC
246	f2	n18	156	1	0	XF218	.	.	0.00000	0.000	.	249	20	NONKEY ARC BASIC
247	g2	n18	164	1	0	XG218	.	.	0.00000	0.000	.	250	21	NONKEY ARC BASIC
248	h2	n18	160	1	0	XH218	.	.	0.00000	0.000	.	251	22	NONKEY ARC BASIC
249	i2	n18	176	1	0	XI218	.	.	0.00000	0.000	.	252	23	NONKEY ARC BASIC
250	j2	n18	175	1	0	XJ218	.	.	0.00000	0.000	.	253	24	NONKEY ARC BASIC
251	k2	n18	107	1	0	XK218	.	.	0.00000	0.000	.	254	25	NONKEY ARC BASIC
252	l2	n18	91	1	0	XL218	.	.	1.00000	91.000	.	255	26	NONKEY ARC BASIC
253	a2	n19	0	1	0	XA219	.	.	0.00000	0.000	.	256	15	NONKEY ARC BASIC
254	b2	n19	182	1	0	XB219	.	.	0.00000	0.000	.	257	16	KEY_ARC BASIC
255	c2	n19	151	1	0	XC219	.	.	1.00000	151.000	.	258	17	NONKEY ARC BASIC
256	d2	n19	166	1	0	XD219	.	.	0.00000	0.000	.	259	18	NONKEY ARC BASIC
257	e2	n19	180	1	0	XE219	.	.	0.00000	0.000	.	260	19	NONKEY ARC BASIC
258	f2	n19	174	1	0	XF219	.	.	0.00000	0.000	.	261	20	NONKEY ARC BASIC
259	g2	n19	180	1	0	XG219	.	.	0.00000	0.000	.	262	21	NONKEY ARC BASIC
260	h2	n19	177	1	0	XH219	.	.	0.00000	0.000	.	263	22	NONKEY ARC BASIC
261	i2	n19	187	1	0	XI219	.	.	0.00000	0.000	.	264	23	NONKEY ARC BASIC
262	j2	n19	185	1	0	XJ219	.	.	0.00000	0.000	-2407	265	24	LOWERBD NONBASIC
263	k2	n19	144	1	0	XK219	.	.	0.00000	0.000	.	266	25	NONKEY ARC BASIC
264	l2	n19	135	1	0	XL219	.	.	1.00000	135.000	.	267	26	NONKEY ARC BASIC
265	a2	n20	60	1	0	XA220	.	.	0.00000	0.000	.	268	15	NONKEY ARC BASIC
266	b2	n20	60	1	0	XB220	.	.	0.00000	0.000	.	269	16	NONKEY ARC BASIC
267	c2	n20	60	1	0	XC220	.	.	1.00000	60.000	.	270	17	KEY_ARC BASIC
268	d2	n20	60	1	0	XD220	.	.	0.00000	0.000	.	271	18	NONKEY ARC BASIC
269	e2	n20	60	1	0	XE220	.	.	0.00000	0.000	.	272	19	NONKEY ARC BASIC
270	f2	n20	60	1	0	XF220	.	.	0.00000	0.000	.	273	20	NONKEY ARC BASIC
271	g2	n20	60	1	0	XG220	.	.	0.00000	0.000	.	274	21	NONKEY ARC BASIC
272	h2	n20	60	1	0	XH220	.	.	0.00000	0.000	.	275	22	NONKEY ARC BASIC
273	i2	n20	60	1	0	XI220	.	.	0.00000	0.000	.	276	23	NONKEY ARC BASIC
274	j2	n20	60	1	0	XJ220	.	.	0.00000	0.000	.	277	24	NONKEY ARC BASIC
275	k2	n20	60	1	0	XK220	.	.	0.00000	0.000	.	278	25	NONKEY ARC BASIC
276	l2	n20	60	1	0	XL220	.	.	1.00000	60.000	.	279	26	NONKEY ARC BASIC
277	a2	n21	36	1	0	XA221	.	.	0.00000	0.000	.	280	15	NONKEY ARC BASIC
278	b2	n21	187	1	0	XB221	.	.	0.00000	0.000	.	281	16	NONKEY ARC BASIC
279	c2	n21	207	1	0	XC221	.	.	1.00000	207.000	.	282	17	NONKEY ARC BASIC
280	d2	n21	212	1	0	XD221	.	.	0.00000	0.000	.	283	18	NONKEY ARC BASIC
281	e2	n21	201	1	0	XE221	.	.	0.00000	0.000	.	284	19	NONKEY ARC BASIC
282	f2	n21	215	1	0	XF221	.	.	0.00000	0.000	.	285	20	KEY_ARC BASIC
283	g2	n21	219	1	0	XG221	.	.	0.00000	0.000	-1951	286	21	LOWERBD NONBASIC
284	h2	n21	217	1	0	XH221	.	.	0.00000	0.000	.	287	22	NONKEY ARC BASIC
285	i2	n21	164	1	0	XI221	.	.	0.00000	0.000	.	288	23	NONKEY ARC BASIC
286	j2	n21	170	1	0	XJ221	.	.	0.00000	0.000	.	289	24	NONKEY ARC BASIC
287	k2	n21	203	1	0	XK221	.	.	0.00000	0.000	.	290	25	NONKEY ARC BASIC
288	l2	n21	200	1	0	XL221	.	.	1.00000	200.000	.	291	26	NONKEY ARC BASIC
289	a2	n22	61	1	0	XA222	.	.	0.00000	0.000	.	292	15	NONKEY ARC BASIC
290	b2	n22	224	1	0	XB222	.	.	0.00000	0.000	.	293	16	NONKEY ARC BASIC
291	c2	n22	197	1	0	XC222	.	.	1.00000	197.000	.	294	17	NONKEY ARC BASIC
292	d2	n22	212	1	0	XD222	.	.	0.00000	0.000	.	295	18	NONKEY ARC BASIC
293	e2	n22	214	1	0	XE222	.	.	0.00000	0.000	.	296	19	NONKEY ARC BASIC
294	f2	n22	212	1	0	XF222	.	.	0.00000	0.000	.	297	20	NONKEY ARC BASIC
295	g2	n22	211	1	0	XG222	.	.	0.00000	0.000	.	298	21	NONKEY ARC BASIC
296	h2	n22	212	1	0	XH222	.	.	0.00000	0.000	.	299	22	NONKEY ARC BASIC
297	i2	n22	213	1	0	XI222	.	.	0.00000	0.000	.	300	23	NONKEY ARC BASIC
298	j2	n22	214	1	0	XJ222	.	.	0.00000	0.000	.	301	24	KEY_ARC BASIC
299	k2	n22	196	1	0	XK222	.	.	0.00000	0.000	.	302	25	NONKEY ARC BASIC
300	l2	n22	190	1	0	XL222	.	.	1.00000	190.000	.	303	26	NONKEY ARC BASIC

OBS	_FROM_	_TO_	_COST_	_CAPAC_	_LO_	_NAME_	_SUPPLY_	_DEMAND_	_FLOW_	_FCOST_	_RCOST_	_ANUMB_	_TNUMB_	_STATUS_
301	a2	n23	300	1	0	XA223	.	.	0	0	-199999700	304	15	LOWERBD NONBASIC
302	b2	n23	240	1	0	XB223	.	.	0	0	.	305	16	NONKEY ARC BASIC
303	c2	n23	251	1	0	XC223	.	.	1	251	.	306	17	NONKEY ARC BASIC
304	d2	n23	246	1	0	XD223	.	.	0	0	.	307	18	NONKEY ARC BASIC
305	e2	n23	238	1	0	XE223	.	.	0	0	.	308	19	NONKEY ARC BASIC
306	f2	n23	242	1	0	XF223	.	.	0	0	.	309	20	NONKEY ARC BASIC
307	g2	n23	240	1	0	XG223	.	.	0	0	.	310	21	NONKEY ARC BASIC
308	h2	n23	241	1	0	XH223	.	.	0	0	.	311	22	NONKEY ARC BASIC
309	i2	n23	237	1	0	XI223	.	.	0	0	.	312	23	NONKEY ARC BASIC
310	j2	n23	237	1	0	XJ223	.	.	0	0	.	313	24	NONKEY ARC BASIC
311	k2	n23	256	1	0	XK223	.	.	0	0	.	314	25	NONKEY ARC BASIC
312	l2	n23	260	1	0	XL223	.	.	1	260	.	315	26	KEY_ARC BASIC
313	a2	n24	300	1	0	XA224	.	.	0	0	.	316	15	NONKEY ARC BASIC
314	b2	n24	239	1	0	XB224	.	.	0	0	.	317	16	NONKEY ARC BASIC
315	c2	n24	252	1	0	XC224	.	.	1	252	.	318	17	NONKEY ARC BASIC
316	d2	n24	246	1	0	XD224	.	.	0	0	.	319	18	NONKEY ARC BASIC
317	e2	n24	240	1	0	XE224	.	.	0	0	.	320	19	NONKEY ARC BASIC
318	f2	n24	243	1	0	XF224	.	.	0	0	.	321	20	NONKEY ARC BASIC
319	g2	n24	240	1	0	XG224	.	.	0	0	.	322	21	NONKEY ARC BASIC
320	h2	n24	241	1	0	XH224	.	.	0	0	.	323	22	NONKEY ARC BASIC
321	i2	n24	238	1	0	XI224	.	.	0	0	.	324	23	NONKEY ARC BASIC
322	j2	n24	239	1	0	XJ224	.	.	0	0	.	325	24	NONKEY ARC BASIC
323	k2	n24	255	1	0	XK224	.	.	0	0	.	326	25	KEY_ARC BASIC
324	l2	n24	261	1	0	XL224	.	.	1	261	.	327	26	NONKEY ARC BASIC
325	a2	n25	300	1	0	XA225	.	.	0	0	.	328	15	NONKEY ARC BASIC
326	b2	n25	214	1	0	XB225	.	.	0	0	.	329	16	NONKEY ARC BASIC
327	c2	n25	290	1	0	XC225	.	.	1	290	.	330	17	NONKEY ARC BASIC
328	d2	n25	277	1	0	XD225	.	.	0	0	.	331	18	NONKEY ARC BASIC
329	e2	n25	219	1	0	XE225	.	.	0	0	.	332	19	NONKEY ARC BASIC
330	f2	n25	250	1	0	XF225	.	.	0	0	.	333	20	NONKEY ARC BASIC
331	g2	n25	224	1	0	XG225	.	.	0	0	.	334	21	NONKEY ARC BASIC
332	h2	n25	232	1	0	XH225	.	.	0	0	.	335	22	NONKEY ARC BASIC
333	i2	n25	200	1	0	XI225	.	.	0	0	.	336	23	NONKEY ARC BASIC
334	j2	n25	205	1	0	XJ225	.	.	0	0	.	337	24	NONKEY ARC BASIC
335	k2	n25	300	1	0	XK225	.	.	0	0	.	338	25	NONKEY ARC BASIC
336	l2	n25	300	1	0	XL225	.	.	1	300	.	339	26	KEY_ARC BASIC
337	a2	n26	300	1	0	XA226	.	.	0	0	.	340	15	NONKEY ARC BASIC
338	b2	n26	163	1	0	XB226	.	.	0	0	.	341	16	NONKEY ARC BASIC
339	c2	n26	215	1	0	XC226	.	.	1	215	.	342	17	NONKEY ARC BASIC
340	d2	n26	185	1	0	XD226	.	.	0	0	.	343	18	NONKEY ARC BASIC
341	e2	n26	163	1	0	XE226	.	.	0	0	.	344	19	NONKEY ARC BASIC
342	f2	n26	173	1	0	XF226	.	.	0	0	.	345	20	NONKEY ARC BASIC
343	g2	n26	166	1	0	XG226	.	.	0	0	.	346	21	NONKEY ARC BASIC
344	h2	n26	169	1	0	XH226	.	.	0	0	.	347	22	NONKEY ARC BASIC
345	i2	n26	153	1	0	XI226	.	.	0	0	.	348	23	NONKEY ARC BASIC
346	j2	n26	155	1	0	XJ226	.	.	0	0	.	349	24	NONKEY ARC BASIC
347	k2	n26	234	1	0	XK226	.	.	0	0	.	350	25	KEY_ARC BASIC
348	l2	n26	254	1	0	XL226	.	.	1	254	.	351	26	NONKEY ARC BASIC
349	a2	n27	300	1	0	XA227	.	.	0	0	.	352	15	NONKEY ARC BASIC
350	b2	n27	157	1	0	XB227	.	.	0	0	.	353	16	NONKEY ARC BASIC
351	c2	n27	215	1	0	XC227	.	.	1	215	.	354	17	NONKEY ARC BASIC
352	d2	n27	180	1	0	XD227	.	.	0	0	.	355	18	NONKEY ARC BASIC
353	e2	n27	155	1	0	XE227	.	.	0	0	.	356	19	NONKEY ARC BASIC
354	f2	n27	166	1	0	XF227	.	.	0	0	.	357	20	NONKEY ARC BASIC
355	g2	n27	154	1	0	XG227	.	.	0	0	.	358	21	NONKEY ARC BASIC
356	h2	n27	158	1	0	XH227	.	.	0	0	.	359	22	NONKEY ARC BASIC
357	i2	n27	144	1	0	XI227	.	.	0	0	-3	360	23	LOWERBD NONBASIC
358	j2	n27	150	1	0	XJ227	.	.	0	0	.	361	24	NONKEY ARC BASIC
359	k2	n27	232	1	0	XK227	.	.	0	0	.	362	25	KEY_ARC BASIC
360	l2	n27	265	1	0	XL227	.	.	1	265	.	363	26	NONKEY ARC BASIC

OBS	_FROM_	_TO_	_COST_	_CAPAC_	_LO_	_NAME_	_SUPPLY_	_DEMAND_	_FLOW_	_FCOST_	_RCOST_	_ANUMB_	_TNUMB_	_STATUS_
361	a2	n28	300	1	0	XA228	.	.	0	0	.	364	15	NONKEY ARC BASIC
362	b2	n28	245	1	0	XB228	.	.	0	0	.	365	16	NONKEY ARC BASIC
363	c2	n28	296	1	0	XC228	.	.	1	296	.	366	17	NONKEY ARC BASIC
364	d2	n28	288	1	0	XD228	.	.	0	0	.	367	18	NONKEY ARC BASIC
365	e2	n28	251	1	0	XE228	.	.	0	0	.	368	19	NONKEY ARC BASIC
366	f2	n28	280	1	0	XF228	.	.	0	0	.	369	20	NONKEY ARC BASIC
367	g2	n28	255	1	0	XG228	.	.	0	0	.	370	21	NONKEY ARC BASIC
368	h2	n28	267	1	0	XH228	.	.	0	0	.	371	22	NONKEY ARC BASIC
369	i2	n28	219	1	0	XI228	.	.	0	0	.	372	23	NONKEY ARC BASIC
370	j2	n28	224	1	0	XJ228	.	.	0	0	.	373	24	NONKEY ARC BASIC
371	k2	n28	300	1	0	XK228	.	.	0	0	-200000036	374	25	LOWERBD NONBASIC
372	l2	n28	300	1	0	XL228	.	.	1	300	.	375	26	KEY_ARC BASIC
373	a2	n29	300	1	0	XA229	.	.	0	0	.	376	15	NONKEY ARC BASIC
374	b2	n29	168	1	0	XB229	.	.	0	0	-14	377	16	LOWERBD NONBASIC
375	c2	n29	243	1	0	XC229	.	.	1	243	.	378	17	NONKEY ARC BASIC
376	d2	n29	202	1	0	XD229	.	.	0	0	.	379	18	NONKEY ARC BASIC
377	e2	n29	173	1	0	XE229	.	.	0	0	.	380	19	NONKEY ARC BASIC
378	f2	n29	186	1	0	XF229	.	.	0	0	.	381	20	NONKEY ARC BASIC
379	g2	n29	174	1	0	XG229	.	.	0	0	.	382	21	NONKEY ARC BASIC
380	h2	n29	177	1	0	XH229	.	.	0	0	.	383	22	NONKEY ARC BASIC
381	i2	n29	162	1	0	XI229	.	.	0	0	.	384	23	NONKEY ARC BASIC
382	j2	n29	162	1	0	XJ229	.	.	0	0	.	385	24	NONKEY ARC BASIC
383	k2	n29	295	1	0	XK229	.	.	0	0	.	386	25	KEY_ARC BASIC
384	l2	n29	299	1	0	XL229	.	.	1	299	.	387	26	NONKEY ARC BASIC
385	a2	n30	300	1	0	XA230	.	.	0	0	.	388	15	NONKEY ARC BASIC
386	b2	n30	168	1	0	XB230	.	.	0	0	-13	389	16	LOWERBD NONBASIC
387	c2	n30	244	1	0	XC230	.	.	1	244	.	390	17	NONKEY ARC BASIC
388	d2	n30	202	1	0	XD230	.	.	0	0	.	391	18	NONKEY ARC BASIC
389	e2	n30	172	1	0	XE230	.	.	0	0	.	392	19	NONKEY ARC BASIC
390	f2	n30	185	1	0	XF230	.	.	0	0	.	393	20	KEY_ARC BASIC
391	g2	n30	172	1	0	XG230	.	.	0	0	.	394	21	NONKEY ARC BASIC
392	h2	n30	178	1	0	XH230	.	.	0	0	.	395	22	NONKEY ARC BASIC
393	i2	n30	161	1	0	XI230	.	.	0	0	-19	396	23	LOWERBD NONBASIC
394	j2	n30	162	1	0	XJ230	.	.	0	0	.	397	24	NONKEY ARC BASIC
395	k2	n30	295	1	0	XK230	.	.	0	0	.	398	25	NONKEY ARC BASIC
396	l2	n30	298	1	0	XL230	.	.	1	298	.	399	26	NONKEY ARC BASIC
397	a2	n31	300	1	0	XA231	.	.	0	0	.	400	15	NONKEY ARC BASIC
398	b2	n31	191	1	0	XB231	.	.	0	0	.	401	16	NONKEY ARC BASIC
399	c2	n31	289	1	0	XC231	.	.	1	289	.	402	17	NONKEY ARC BASIC
400	d2	n31	237	1	0	XD231	.	.	0	0	.	403	18	NONKEY ARC BASIC
401	e2	n31	196	1	0	XE231	.	.	0	0	.	404	19	NONKEY ARC BASIC
402	f2	n31	214	1	0	XF231	.	.	0	0	.	405	20	NONKEY ARC BASIC
403	g2	n31	198	1	0	XG231	.	.	0	0	.	406	21	NONKEY ARC BASIC
404	h2	n31	205	1	0	XH231	.	.	0	0	.	407	22	NONKEY ARC BASIC
405	i2	n31	180	1	0	XI231	.	.	0	0	.	408	23	NONKEY ARC BASIC
406	j2	n31	182	1	0	XJ231	.	.	0	0	.	409	24	NONKEY ARC BASIC
407	k2	n31	293	1	0	XK231	.	.	0	0	.	410	25	KEY_ARC BASIC
408	l2	n31	298	1	0	XL231	.	.	1	298	.	411	26	NONKEY ARC BASIC
409	a2	n32	300	1	0	XA232	.	.	0	0	.	412	15	NONKEY ARC BASIC
410	b2	n32	181	1	0	XB232	.	.	0	0	.	413	16	NONKEY ARC BASIC
411	c2	n32	292	1	0	XC232	.	.	1	292	.	414	17	NONKEY ARC BASIC
412	d2	n32	221	1	0	XD232	.	.	0	0	.	415	18	NONKEY ARC BASIC
413	e2	n32	185	1	0	XE232	.	.	0	0	.	416	19	NONKEY ARC BASIC
414	f2	n32	200	1	0	XF232	.	.	0	0	.	417	20	NONKEY ARC BASIC
415	g2	n32	186	1	0	XG232	.	.	0	0	.	418	21	NONKEY ARC BASIC
416	h2	n32	192	1	0	XH232	.	.	0	0	.	419	22	NONKEY ARC BASIC
417	i2	n32	174	1	0	XI232	.	.	0	0	.	420	23	NONKEY ARC BASIC
418	j2	n32	176	1	0	XJ232	.	.	0	0	.	421	24	NONKEY ARC BASIC
419	k2	n32	295	1	0	XK232	.	.	0	0	.	422	25	KEY_ARC BASIC
420	l2	n32	298	1	0	XL232	.	.	1	298	.	423	26	NONKEY ARC BASIC

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421	a3	n33	0	1	0	XA333	.	.	0	0	.	424	28	NONKEY ARC BASIC
422	b3	n33	139	1	0	XB333	.	.	0	0	.	425	29	KEY_ARC BASIC
423	c3	n33	47	1	0	XC333	.	.	1	47	.	426	30	NONKEY ARC BASIC
424	d3	n33	100	1	0	XD333	.	.	0	0	.	427	31	NONKEY ARC BASIC
425	e3	n33	134	1	0	XE333	.	.	0	0	.	428	32	NONKEY ARC BASIC
426	f3	n33	119	1	0	XF333	.	.	0	0	.	429	33	NONKEY ARC BASIC
427	g3	n33	132	1	0	XG333	.	.	0	0	.	430	34	NONKEY ARC BASIC
428	h3	n33	127	1	0	XH333	.	.	0	0	.	431	35	NONKEY ARC BASIC
429	i3	n33	148	1	0	XI333	.	.	0	0	.	432	36	NONKEY ARC BASIC
430	j3	n33	144	1	0	XJ333	.	.	0	0	.	433	37	NONKEY ARC BASIC
431	k3	n33	0	1	0	XK333	.	.	0	0	.	434	38	NONKEY ARC BASIC
432	l3	n33	0	1	0	XL333	.	.	1	0	.	435	39	NONKEY ARC BASIC
433	a3	n34	64	1	0	XA334	.	.	0	0	.	436	28	NONKEY ARC BASIC
434	b3	n34	64	1	0	XB334	.	.	0	0	.	437	29	NONKEY ARC BASIC
435	c3	n34	64	1	0	XC334	.	.	1	64	.	438	30	NONKEY ARC BASIC
436	d3	n34	64	1	0	XD334	.	.	0	0	.	439	31	NONKEY ARC BASIC
437	e3	n34	64	1	0	XE334	.	.	0	0	.	440	32	NONKEY ARC BASIC
438	f3	n34	64	1	0	XF334	.	.	0	0	.	441	33	KEY_ARC BASIC
439	g3	n34	64	1	0	XG334	.	.	0	0	.	442	34	NONKEY ARC BASIC
440	h3	n34	64	1	0	XH334	.	.	0	0	.	443	35	NONKEY ARC BASIC
441	i3	n34	60	1	0	XI334	.	.	0	0	.	444	36	NONKEY ARC BASIC
442	j3	n34	56	1	0	XJ334	.	.	0	0	.	445	37	NONKEY ARC BASIC
443	k3	n34	64	1	0	XK334	.	.	0	0	.	446	38	NONKEY ARC BASIC
444	l3	n34	64	1	0	XL334	.	.	1	64	.	447	39	NONKEY ARC BASIC
445	a3	n35	62	1	0	XA335	.	.	0	0	.	448	28	NONKEY ARC BASIC
446	b3	n35	57	1	0	XB335	.	.	0	0	.	449	29	NONKEY ARC BASIC
447	c3	n35	59	1	0	XC335	.	.	1	59	.	450	30	NONKEY ARC BASIC
448	d3	n35	67	1	0	XD335	.	.	0	0	.	451	31	NONKEY ARC BASIC
449	e3	n35	61	1	0	XE335	.	.	0	0	-2130	452	32	LOWERBD NONBASIC
450	f3	n35	61	1	0	XF335	.	.	0	0	.	453	33	NONKEY ARC BASIC
451	g3	n35	62	1	0	XG335	.	.	0	0	.	454	34	KEY_ARC BASIC
452	h3	n35	62	1	0	XH335	.	.	0	0	-1857	455	35	LOWERBD NONBASIC
453	i3	n35	56	1	0	XI335	.	.	0	0	.	456	36	NONKEY ARC BASIC
454	j3	n35	56	1	0	XJ335	.	.	0	0	.	457	37	NONKEY ARC BASIC
455	k3	n35	62	1	0	XK335	.	.	0	0	.	458	38	NONKEY ARC BASIC
456	l3	n35	55	1	0	XL335	.	.	1	55	.	459	39	NONKEY ARC BASIC
457	a3	n36	60	1	0	XA336	.	.	0	0	.	460	28	NONKEY ARC BASIC
458	b3	n36	60	1	0	XB336	.	.	0	0	.	461	29	NONKEY ARC BASIC
459	c3	n36	60	1	0	XC336	.	.	1	60	.	462	30	NONKEY ARC BASIC
460	d3	n36	90	1	0	XD336	.	.	0	0	.	463	31	NONKEY ARC BASIC
461	e3	n36	60	1	0	XE336	.	.	0	0	.	464	32	NONKEY ARC BASIC
462	f3	n36	90	1	0	XF336	.	.	0	0	.	465	33	NONKEY ARC BASIC
463	g3	n36	90	1	0	XG336	.	.	0	0	.	466	34	KEY_ARC BASIC
464	h3	n36	90	1	0	XH336	.	.	0	0	.	467	35	NONKEY ARC BASIC
465	i3	n36	90	1	0	XI336	.	.	0	0	.	468	36	NONKEY ARC BASIC
466	j3	n36	60	1	0	XJ336	.	.	0	0	.	469	37	NONKEY ARC BASIC
467	k3	n36	60	1	0	XK336	.	.	0	0	.	470	38	NONKEY ARC BASIC
468	l3	n36	60	1	0	XL336	.	.	1	60	60	471	39	UPPERBD NONBASIC
469	a3	n37	300	1	0	XA337	.	.	0	0	.	472	28	NONKEY ARC BASIC
470	b3	n37	243	1	0	XB337	.	.	0	0	.	473	29	NONKEY ARC BASIC
471	c3	n37	244	1	0	XC337	.	.	1	244	.	474	30	KEY_ARC BASIC
472	d3	n37	244	1	0	XD337	.	.	0	0	.	475	31	NONKEY ARC BASIC
473	e3	n37	222	1	0	XE337	.	.	0	0	.	476	32	NONKEY ARC BASIC
474	f3	n37	244	1	0	XF337	.	.	0	0	.	477	33	NONKEY ARC BASIC
475	g3	n37	244	1	0	XG337	.	.	0	0	.	478	34	NONKEY ARC BASIC
476	h3	n37	214	1	0	XH337	.	.	0	0	.	479	35	NONKEY ARC BASIC
477	i3	n37	183	1	0	XI337	.	.	0	0	.	480	36	NONKEY ARC BASIC
478	j3	n37	243	1	0	XJ337	.	.	0	0	.	481	37	NONKEY ARC BASIC
479	k3	n37	244	1	0	XK337	.	.	0	0	.	482	38	NONKEY ARC BASIC
480	l3	n37	244	1	0	XL337	.	.	1	244	.	483	39	NONKEY ARC BASIC

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481	a3	n38	214	1	0	XA338	.	.	0	0	.	484	28	NONKEY ARC BASIC
482	b3	n38	148	1	0	XB338	.	.	0	0	.	485	29	NONKEY ARC BASIC
483	c3	n38	164	1	0	XC338	.	.	1	164	.	486	30	NONKEY ARC BASIC
484	d3	n38	155	1	0	XD338	.	.	0	0	.	487	31	NONKEY ARC BASIC
485	e3	n38	149	1	0	XE338	.	.	0	0	.	488	32	NONKEY ARC BASIC
486	f3	n38	152	1	0	XF338	.	.	0	0	.	489	33	NONKEY ARC BASIC
487	g3	n38	149	1	0	XG338	.	.	0	0	.	490	34	NONKEY ARC BASIC
488	h3	n38	150	1	0	XH338	.	.	0	0	.	491	35	NONKEY ARC BASIC
489	i3	n38	145	1	0	XI338	.	.	0	0	.	492	36	NONKEY ARC BASIC
490	j3	n38	148	1	0	XJ338	.	.	0	0	.	493	37	NONKEY ARC BASIC
491	k3	n38	169	1	0	XK338	.	.	0	0	.	494	38	KEY_ARC BASIC
492	l3	n38	173	1	0	XL338	.	.	1	173	.	495	39	NONKEY ARC BASIC
493	a3	n39	300	1	0	XA339	.	.	0	0	.	496	28	NONKEY ARC BASIC
494	b3	n39	149	1	0	XB339	.	.	0	0	.	497	29	NONKEY ARC BASIC
495	c3	n39	214	1	0	XC339	.	.	1	214	.	498	30	NONKEY ARC BASIC
496	d3	n39	180	1	0	XD339	.	.	0	0	.	499	31	NONKEY ARC BASIC
497	e3	n39	154	1	0	XE339	.	.	0	0	.	500	32	NONKEY ARC BASIC
498	f3	n39	167	1	0	XF339	.	.	0	0	.	501	33	NONKEY ARC BASIC
499	g3	n39	158	1	0	XG339	.	.	0	0	.	502	34	NONKEY ARC BASIC
500	h3	n39	159	1	0	XH339	.	.	0	0	.	503	35	NONKEY ARC BASIC
501	i3	n39	147	1	0	XI339	.	.	0	0	.	504	36	NONKEY ARC BASIC
502	j3	n39	149	1	0	XJ339	.	.	0	0	.	505	37	NONKEY ARC BASIC
503	k3	n39	232	1	0	XK339	.	.	0	0	.	506	38	NONKEY ARC BASIC
504	l3	n39	250	1	0	XL339	.	.	1	250	.	507	39	KEY_ARC BASIC
505	a3	n40	300	1	0	XA340	.	.	0	0	.	508	28	NONKEY ARC BASIC
506	b3	n40	191	1	0	XB340	.	.	0	0	.	509	29	NONKEY ARC BASIC
507	c3	n40	300	1	0	XC340	.	.	1	300	.	510	30	NONKEY ARC BASIC
508	d3	n40	230	1	0	XD340	.	.	0	0	.	511	31	NONKEY ARC BASIC
509	e3	n40	180	1	0	XE340	.	.	0	0	.	512	32	NONKEY ARC BASIC
510	f3	n40	215	1	0	XF340	.	.	0	0	.	513	33	NONKEY ARC BASIC
511	g3	n40	193	1	0	XG340	.	.	0	0	.	514	34	NONKEY ARC BASIC
512	h3	n40	182	1	0	XH340	.	.	0	0	.	515	35	NONKEY ARC BASIC
513	i3	n40	179	1	0	XI340	.	.	0	0	.	516	36	NONKEY ARC BASIC
514	j3	n40	180	1	0	XJ340	.	.	0	0	.	517	37	NONKEY ARC BASIC
515	k3	n40	290	1	0	XK340	.	.	0	0	.	518	38	NONKEY ARC BASIC
516	l3	n40	298	1	0	XL340	.	.	1	298	.	519	39	KEY_ARC BASIC
517	a3	n41	300	1	0	XA341	.	.	0	0	.	520	28	NONKEY ARC BASIC
518	b3	n41	186	1	0	XB341	.	.	0	0	.	521	29	NONKEY ARC BASIC
519	c3	n41	284	1	0	XC341	.	.	1	284	.	522	30	NONKEY ARC BASIC
520	d3	n41	234	1	0	XD341	.	.	0	0	.	523	31	NONKEY ARC BASIC
521	e3	n41	199	1	0	XE341	.	.	0	0	.	524	32	NONKEY ARC BASIC
522	f3	n41	211	1	0	XF341	.	.	0	0	.	525	33	NONKEY ARC BASIC
523	g3	n41	203	1	0	XG341	.	.	0	0	.	526	34	NONKEY ARC BASIC
524	h3	n41	212	1	0	XH341	.	.	0	0	.	527	35	NONKEY ARC BASIC
525	i3	n41	178	1	0	XI341	.	.	0	0	.	528	36	NONKEY ARC BASIC
526	j3	n41	179	1	0	XJ341	.	.	0	0	.	529	37	NONKEY ARC BASIC
527	k3	n41	296	1	0	XK341	.	.	0	0	.	530	38	KEY_ARC BASIC
528	l3	n41	298	1	0	XL341	.	.	1	298	.	531	39	NONKEY ARC BASIC
529	a3	n42	300	1	0	XA342	.	.	0	0	.	532	28	NONKEY ARC BASIC
530	b3	n42	144	1	0	XB342	.	.	0	0	.	533	29	NONKEY ARC BASIC
531	c3	n42	192	1	0	XC342	.	.	1	192	.	534	30	NONKEY ARC BASIC
532	d3	n42	168	1	0	XD342	.	.	0	0	.	535	31	NONKEY ARC BASIC
533	e3	n42	142	1	0	XE342	.	.	0	0	.	536	32	NONKEY ARC BASIC
534	f3	n42	153	1	0	XF342	.	.	0	0	.	537	33	NONKEY ARC BASIC
535	g3	n42	144	1	0	XG342	.	.	0	0	.	538	34	NONKEY ARC BASIC
536	h3	n42	150	1	0	XH342	.	.	0	0	.	539	35	NONKEY ARC BASIC
537	i3	n42	133	1	0	XI342	.	.	0	0	.	540	36	NONKEY ARC BASIC
538	j3	n42	133	1	0	XJ342	.	.	0	0	.	541	37	NONKEY ARC BASIC
539	k3	n42	204	1	0	XK342	.	.	0	0	.	542	38	KEY_ARC BASIC
540	l3	n42	228	1	0	XL342	.	.	1	228	.	543	39	NONKEY ARC BASIC

OBS	_FROM_	_TO_	_COST_	_CAPAC_	_LO_	_NAME_	_SUPPLY_	_DEMAND_	_FLOW_	_FCOST_	_RCOST_	_ANUMB_	_TNUMB_	_STATUS_
541	a3	n43	300	1	0	XA343	.	.	0	0	.	544	28	NONKEY ARC BASIC
542	b3	n43	158	1	0	XB343	.	.	0	0	-2147	545	29	LOWERBD NONBASIC
543	c3	n43	222	1	0	XC343	.	.	1	222	.	546	30	NONKEY ARC BASIC
544	d3	n43	189	1	0	XD343	.	.	0	0	.	547	31	NONKEY ARC BASIC
545	e3	n43	162	1	0	XE343	.	.	0	0	.	548	32	NONKEY ARC BASIC
546	f3	n43	173	1	0	XF343	.	.	0	0	.	549	33	NONKEY ARC BASIC
547	g3	n43	164	1	0	XG343	.	.	0	0	.	550	34	NONKEY ARC BASIC
548	h3	n43	168	1	0	XH343	.	.	0	0	.	551	35	NONKEY ARC BASIC
549	i3	n43	155	1	0	XI343	.	.	0	0	.	552	36	NONKEY ARC BASIC
550	j3	n43	153	1	0	XJ343	.	.	0	0	.	553	37	NONKEY ARC BASIC
551	k3	n43	251	1	0	XK343	.	.	0	0	.	554	38	KEY_ARC BASIC
552	l3	n43	300	1	0	XL343	.	.	1	300	.	555	39	NONKEY ARC BASIC
553	a3	n44	300	1	0	XA344	.	.	0	0	.	556	28	NONKEY ARC BASIC
554	b3	n44	182	1	0	XB344	.	.	0	0	.	557	29	NONKEY ARC BASIC
555	c3	n44	290	1	0	XC344	.	.	1	290	.	558	30	NONKEY ARC BASIC
556	d3	n44	226	1	0	XD344	.	.	0	0	.	559	31	NONKEY ARC BASIC
557	e3	n44	188	1	0	XE344	.	.	0	0	.	560	32	NONKEY ARC BASIC
558	f3	n44	206	1	0	XF344	.	.	0	0	.	561	33	NONKEY ARC BASIC
559	g3	n44	191	1	0	XG344	.	.	0	0	.	562	34	NONKEY ARC BASIC
560	h3	n44	196	1	0	XH344	.	.	0	0	.	563	35	NONKEY ARC BASIC
561	i3	n44	173	1	0	XI344	.	.	0	0	-2426	564	36	LOWERBD NONBASIC
562	j3	n44	176	1	0	XJ344	.	.	0	0	.	565	37	NONKEY ARC BASIC
563	k3	n44	294	1	0	XK344	.	.	0	0	.	566	38	KEY_ARC BASIC
564	l3	n44	297	1	0	XL344	.	.	1	297	.	567	39	NONKEY ARC BASIC
565	a3	n45	300	1	0	XA345	.	.	0	0	.	568	28	NONKEY ARC BASIC
566	b3	n45	182	1	0	XB345	.	.	0	0	.	569	29	NONKEY ARC BASIC
567	c3	n45	288	1	0	XC345	.	.	1	288	.	570	30	NONKEY ARC BASIC
568	d3	n45	226	1	0	XD345	.	.	0	0	.	571	31	NONKEY ARC BASIC
569	e3	n45	186	1	0	XE345	.	.	0	0	.	572	32	NONKEY ARC BASIC
570	f3	n45	200	1	0	XF345	.	.	0	0	.	573	33	NONKEY ARC BASIC
571	g3	n45	187	1	0	XG345	.	.	0	0	.	574	34	NONKEY ARC BASIC
572	h3	n45	194	1	0	XH345	.	.	0	0	.	575	35	NONKEY ARC BASIC
573	i3	n45	173	1	0	XI345	.	.	0	0	.	576	36	NONKEY ARC BASIC
574	j3	n45	176	1	0	XJ345	.	.	0	0	.	577	37	NONKEY ARC BASIC
575	k3	n45	292	1	0	XK345	.	.	0	0	.	578	38	KEY_ARC BASIC
576	l3	n45	297	1	0	XL345	.	.	1	297	.	579	39	NONKEY ARC BASIC
577	a3	n46	300	1	0	XA346	.	.	0	0	-2899999656	580	28	LOWERBD NONBASIC
578	b3	n46	164	1	0	XB346	.	.	0	0	.	581	29	NONKEY ARC BASIC
579	c3	n46	236	1	0	XC346	.	.	1	236	.	582	30	NONKEY ARC BASIC
580	d3	n46	194	1	0	XD346	.	.	0	0	.	583	31	NONKEY ARC BASIC
581	e3	n46	167	1	0	XE346	.	.	0	0	.	584	32	NONKEY ARC BASIC
582	f3	n46	182	1	0	XF346	.	.	0	0	.	585	33	NONKEY ARC BASIC
583	g3	n46	168	1	0	XG346	.	.	0	0	.	586	34	NONKEY ARC BASIC
584	h3	n46	174	1	0	XH346	.	.	0	0	.	587	35	NONKEY ARC BASIC
585	i3	n46	158	1	0	XI346	.	.	0	0	.	588	36	NONKEY ARC BASIC
586	j3	n46	160	1	0	XJ346	.	.	0	0	.	589	37	NONKEY ARC BASIC
587	k3	n46	271	1	0	XK346	.	.	0	0	.	590	38	KEY_ARC BASIC
588	l3	n46	299	1	0	XL346	.	.	1	299	.	591	39	NONKEY ARC BASIC
589	a3	n47	300	1	0	XA347	.	.	0	0	.	592	28	NONKEY ARC BASIC
590	b3	n47	149	1	0	XB347	.	.	0	0	.	593	29	NONKEY ARC BASIC
591	c3	n47	199	1	0	XC347	.	.	1	199	.	594	30	NONKEY ARC BASIC
592	d3	n47	172	1	0	XD347	.	.	0	0	.	595	31	NONKEY ARC BASIC
593	e3	n47	148	1	0	XE347	.	.	0	0	.	596	32	NONKEY ARC BASIC
594	f3	n47	161	1	0	XF347	.	.	0	0	.	597	33	NONKEY ARC BASIC
595	g3	n47	149	1	0	XG347	.	.	0	0	.	598	34	NONKEY ARC BASIC
596	h3	n47	154	1	0	XH347	.	.	0	0	.	599	35	NONKEY ARC BASIC
597	i3	n47	141	1	0	XI347	.	.	0	0	.	600	36	NONKEY ARC BASIC
598	j3	n47	144	1	0	XJ347	.	.	0	0	.	601	37	NONKEY ARC BASIC
599	k3	n47	215	1	0	XK347	.	.	0	0	.	602	38	KEY_ARC BASIC
600	l3	n47	230	1	0	XL347	.	.	1	230	.	603	39	NONKEY ARC BASIC

OBS	_FROM_	_TO_	_COST_	_CAPAC_	_LO_	_NAME_	_SUPPLY_	_DEMAND_	_FLOW_	_FCOST_	_RCOST_	_ANUMB_	_TNUMB_	_STATUS_
601	a3	n48	165	1	0	XA348	.	.	0	0	.	604	28	NONKEY ARC BASIC
602	b3	n48	159	1	0	XB348	.	.	0	0	.	605	29	NONKEY ARC BASIC
603	c3	n48	165	1	0	XC348	.	.	1	165	.	606	30	NONKEY ARC BASIC
604	d3	n48	165	1	0	XD348	.	.	0	0	.	607	31	KEY_ARC BASIC
605	e3	n48	155	1	0	XE348	.	.	0	0	.	608	32	NONKEY ARC BASIC
606	f3	n48	163	1	0	XF348	.	.	0	0	.	609	33	NONKEY ARC BASIC
607	g3	n48	158	1	0	XG348	.	.	0	0	.	610	34	NONKEY ARC BASIC
608	h3	n48	162	1	0	XH348	.	.	0	0	.	611	35	NONKEY ARC BASIC
609	i3	n48	147	1	0	XI348	.	.	0	0	.	612	36	NONKEY ARC BASIC
610	j3	n48	155	1	0	XJ348	.	.	0	0	.	613	37	NONKEY ARC BASIC
611	k3	n48	165	1	0	XK348	.	.	0	0	.	614	38	NONKEY ARC BASIC
612	l3	n48	165	1	0	XL348	.	.	1	165	.	615	39	NONKEY ARC BASIC
613	t	s1	0	99999999	0	XTS1	.	.	32	0	.	1	88	KEY_ARC BASIC
614	t	s2	0	99999999	0	XTS2	.	.	32	0	.	14	88	KEY_ARC BASIC
615	t	s3	0	99999999	0	XTS3	.	.	32	0	.	27	88	KEY_ARC BASIC
616	n01	t	0	2	0	X01T	.	D	2	0	.	616	40	NONKEY ARC BASIC
617	n02	t	0	2	0	X02T	.	D	2	0	.	617	41	NONKEY ARC BASIC
618	n03	t	0	2	0	X03T	.	D	2	0	.	618	42	NONKEY ARC BASIC
619	n04	t	0	2	0	X04T	.	D	2	0	.	619	43	NONKEY ARC BASIC
620	n05	t	0	2	0	X05T	.	D	2	0	.	620	44	NONKEY ARC BASIC
621	n06	t	0	2	0	X06T	.	D	2	0	.	621	45	NONKEY ARC BASIC
622	n07	t	0	2	0	X07T	.	D	2	0	.	622	46	NONKEY ARC BASIC
623	n08	t	0	2	0	X08T	.	D	2	0	.	623	47	NONKEY ARC BASIC
624	n09	t	0	2	0	X09T	.	D	2	0	.	624	48	NONKEY ARC BASIC
625	n10	t	0	2	0	X10T	.	D	2	0	.	625	49	NONKEY ARC BASIC
626	n11	t	0	2	0	X11T	.	D	2	0	.	626	50	NONKEY ARC BASIC
627	n12	t	0	2	0	X12T	.	D	2	0	.	627	51	NONKEY ARC BASIC
628	n13	t	0	2	0	X13T	.	D	2	0	1861	628	52	UPPERBD NONBASIC
629	n14	t	0	2	0	X14T	.	D	2	0	1349	629	53	UPPERBD NONBASIC
630	n15	t	0	2	0	X15T	.	D	2	0	.	630	54	NONKEY ARC BASIC
631	n16	t	0	2	0	X16T	.	D	2	0	.	631	55	NONKEY ARC BASIC
632	n17	t	0	2	0	X17T	.	D	2	0	.	632	56	NONKEY ARC BASIC
633	n18	t	0	2	0	X18T	.	D	2	0	91	633	57	UPPERBD NONBASIC
634	n19	t	0	2	0	X19T	.	D	2	0	135	634	58	UPPERBD NONBASIC
635	n20	t	0	2	0	X20T	.	D	2	0	60	635	59	UPPERBD NONBASIC
636	n21	t	0	2	0	X21T	.	D	2	0	200	636	60	UPPERBD NONBASIC
637	n22	t	0	2	0	X22T	.	D	2	0	190	637	61	UPPERBD NONBASIC
638	n23	t	0	2	0	X23T	.	D	2	0	260	638	62	UPPERBD NONBASIC
639	n24	t	0	2	0	X24T	.	D	2	0	261	639	63	UPPERBD NONBASIC
640	n25	t	0	2	0	X25T	.	D	2	0	300	640	64	UPPERBD NONBASIC
641	n26	t	0	2	0	X26T	.	D	2	0	254	641	65	UPPERBD NONBASIC
642	n27	t	0	2	0	X27T	.	D	2	0	265	642	66	UPPERBD NONBASIC
643	n28	t	0	2	0	X28T	.	D	2	0	300	643	67	UPPERBD NONBASIC
644	n29	t	0	2	0	X29T	.	D	2	0	299	644	68	UPPERBD NONBASIC
645	n30	t	0	2	0	X30T	.	D	2	0	298	645	69	UPPERBD NONBASIC
646	n31	t	0	2	0	X31T	.	D	2	0	298	646	70	UPPERBD NONBASIC
647	n32	t	0	2	0	X32T	.	D	2	0	298	647	71	UPPERBD NONBASIC
648	n33	t	0	2	0	X33T	.	D	2	0	.	648	72	NONKEY ARC BASIC
649	n34	t	0	2	0	X34T	.	D	2	0	64	649	73	UPPERBD NONBASIC
650	n35	t	0	2	0	X35T	.	D	2	0	55	650	74	UPPERBD NONBASIC
651	n36	t	0	2	0	X36T	.	D	2	0	.	651	75	NONKEY ARC BASIC
652	n37	t	0	2	0	X37T	.	D	2	0	244	652	76	UPPERBD NONBASIC
653	n38	t	0	2	0	X38T	.	D	2	0	173	653	77	UPPERBD NONBASIC
654	n39	t	0	2	0	X39T	.	D	2	0	250	654	78	UPPERBD NONBASIC
655	n40	t	0	2	0	X40T	.	D	2	0	298	655	79	UPPERBD NONBASIC
656	n41	t	0	2	0	X41T	.	D	2	0	298	656	80	UPPERBD NONBASIC
657	n42	t	0	2	0	X42T	.	D	2	0	228	657	81	UPPERBD NONBASIC
658	n43	t	0	2	0	X43T	.	D	2	0	300	658	82	UPPERBD NONBASIC
659	n44	t	0	2	0	X44T	.	D	2	0	297	659	83	UPPERBD NONBASIC
660	n45	t	0	2	0	X45T	.	D	2	0	297	660	84	UPPERBD NONBASIC

OBS	_FROM_	_TO_	_COST_	_CAPAC_	_LO_	_NAME_	_SUPPLY_	_DEMAND_	_FLOW_	_FCOST_	_RCOST_	_ANUMB_	_TNUMB_	_STATUS_
661	n46	t	0	2	0	X46T	.	D	2	0	299	661	85	UPPERBD NONBASIC
662	n47	t	0	2	0	X47T	.	D	2	0	230	662	86	UPPERBD NONBASIC
663	n48	t	0	2	0	X48T	.	D	2	0	165	663	87	UPPERBD NONBASIC
664			0	99999999	0	XS1A2	.	.	0	0	.	0	.	NONKEY BASIC
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W.4 *Solution for $p = 3$*

OBS	_FROM_	_TO_	_COST_	_CAPAC_	_LO_	_NAME_	_SUPPLY_	_DEMAND_	_FLOW_	_FCOST_	_RCOST_	_ANUMB_	_TNUMB_	_STATUS_
1	s1	a1	0	16	0	XS1A1	.	.	16	0	.	2	1	KEY_ARC BASIC
2	s2	a2	0	16	0	XS2A2	.	.	16	0	.	15	14	KEY_ARC BASIC
3	s3	a3	0	16	0	XS3A3	.	.	16	0	.	28	27	KEY_ARC BASIC
4	s1	b1	0	16	0	XS1B1	.	.	0	0	.	3	1	KEY_ARC BASIC
5	s2	b2	0	16	0	XS2B2	.	.	0	0	.	16	14	KEY_ARC BASIC
6	s3	b3	0	16	0	XS3B3	.	.	0	0	.	29	27	KEY_ARC BASIC
7	s1	c1	0	16	0	XS1C1	.	.	16	0	.	4	1	KEY_ARC BASIC
8	s2	c2	0	16	0	XS2C2	.	.	16	0	.	17	14	KEY_ARC BASIC
9	s3	c3	0	16	0	XS3C3	.	.	16	0	.	30	27	KEY_ARC BASIC
10	s1	d1	0	16	0	XS1D1	.	.	0	0	.	5	1	KEY_ARC BASIC
11	s2	d2	0	16	0	XS2D2	.	.	0	0	.	18	14	KEY_ARC BASIC
12	s3	d3	0	16	0	XS3D3	.	.	0	0	.	31	27	KEY_ARC BASIC
13	s1	e1	0	16	0	XS1E1	.	.	0	0	.	6	1	KEY_ARC BASIC
14	s2	e2	0	16	0	XS2E2	.	.	0	0	.	19	14	NONKEY ARC BASIC
15	s3	e3	0	16	0	XS3E3	.	.	0	0	.	32	27	NONKEY ARC BASIC
16	s1	f1	0	16	0	XS1F1	.	.	0	0	.	7	1	KEY_ARC BASIC
17	s2	f2	0	16	0	XS2F2	.	.	0	0	.	20	14	KEY_ARC BASIC
18	s3	f3	0	16	0	XS3F3	.	.	0	0	.	33	27	KEY_ARC BASIC
19	s1	g1	0	16	0	XS1G1	.	.	0	0	.	8	1	KEY_ARC BASIC
20	s2	g2	0	16	0	XS2G2	.	.	0	0	.	21	14	KEY_ARC BASIC
21	s3	g3	0	16	0	XS3G3	.	.	0	0	.	34	27	KEY_ARC BASIC
22	s1	h1	0	16	0	XS1H1	.	.	0	0	.	9	1	KEY_ARC BASIC
23	s2	h2	0	16	0	XS2H2	.	.	0	0	.	22	14	KEY_ARC BASIC
24	s3	h3	0	16	0	XS3H3	.	.	0	0	.	35	27	KEY_ARC BASIC
25	s1	i1	0	16	0	XS1I1	.	.	0	0	.	10	1	KEY_ARC BASIC
26	s2	i2	0	16	0	XS2I2	.	.	0	0	.	23	14	KEY_ARC BASIC
27	s3	i3	0	16	0	XS3I3	.	.	0	0	.	36	27	KEY_ARC BASIC
28	s1	j1	0	16	0	XS1J1	.	.	0	0	.	11	1	KEY_ARC BASIC
29	s2	j2	0	16	0	XS2J2	.	.	0	0	.	24	14	KEY_ARC BASIC
30	s3	j3	0	16	0	XS3J3	.	.	0	0	.	37	27	NONKEY ARC BASIC
31	s1	k1	0	16	0	XS1K1	.	.	0	0	.	12	1	KEY_ARC BASIC
32	s2	k2	0	16	0	XS2K2	.	.	0	0	.	25	14	KEY_ARC BASIC
33	s3	k3	0	16	0	XS3K3	.	.	0	0	.	38	27	KEY_ARC BASIC
34	s1	l1	0	16	0	XS1L1	.	.	16	0	.	13	1	KEY_ARC BASIC
35	s2	l2	0	16	0	XS2L2	.	.	16	0	.	26	14	KEY_ARC BASIC
36	s3	l3	0	16	0	XS3L3	.	.	16	0	.	39	27	KEY_ARC BASIC
37	a1	n01	0	1	0	XA101	.	.	1	0	.	40	2	NONKEY ARC BASIC
38	b1	n01	160	1	0	XB101	.	.	0	0	.	41	3	NONKEY ARC BASIC
39	c1	n01	108	1	0	XC101	.	.	1	108	.	42	4	NONKEY ARC BASIC
40	d1	n01	134	1	0	XD101	.	.	0	0	-88	43	5	LOWERBD NONBASIC
41	e1	n01	157	1	0	XE101	.	.	0	0	.	44	6	KEY_ARC BASIC
42	f1	n01	148	1	0	XF101	.	.	0	0	-38	45	7	LOWERBD NONBASIC
43	g1	n01	157	1	0	XG101	.	.	0	0	.	46	8	NONKEY ARC BASIC
44	h1	n01	155	1	0	XH101	.	.	0	0	-26	47	9	LOWERBD NONBASIC
45	i1	n01	167	1	0	XI101	.	.	0	0	-31	48	10	LOWERBD NONBASIC
46	j1	n01	165	1	0	XJ101	.	.	0	0	.	49	11	NONKEY ARC BASIC
47	k1	n01	90	1	0	XK101	.	.	0	0	-530	50	12	LOWERBD NONBASIC
48	l1	n01	70	1	0	XL101	.	.	1	70	.	51	13	NONKEY ARC BASIC
49	a1	n02	60	1	0	XA102	.	.	1	60	.	52	2	NONKEY ARC BASIC
50	b1	n02	60	1	0	XB102	.	.	0	0	.	53	3	NONKEY ARC BASIC
51	c1	n02	60	1	0	XC102	.	.	1	60	.	54	4	NONKEY ARC BASIC
52	d1	n02	60	1	0	XD102	.	.	0	0	.	55	5	KEY_ARC BASIC
53	e1	n02	60	1	0	XE102	.	.	0	0	.	56	6	NONKEY ARC BASIC
54	f1	n02	60	1	0	XF102	.	.	0	0	.	57	7	NONKEY ARC BASIC
55	g1	n02	60	1	0	XG102	.	.	0	0	.	58	8	NONKEY ARC BASIC
56	h1	n02	60	1	0	XH102	.	.	0	0	.	59	9	NONKEY ARC BASIC
57	i1	n02	60	1	0	XI102	.	.	0	0	.	60	10	NONKEY ARC BASIC
58	j1	n02	60	1	0	XJ102	.	.	0	0	.	61	11	NONKEY ARC BASIC
59	k1	n02	60	1	0	XK102	.	.	0	0	-275	62	12	LOWERBD NONBASIC
60	l1	n02	60	1	0	XL102	.	.	1	60	.	63	13	NONKEY ARC BASIC

OBS	_FROM_	_TO_	_COST_	_CAPAC_	_LO_	_NAME_	_SUPPLY_	_DEMAND_	_FLOW_	_FCOST_	_RCOST_	_ANUMB_	_TNUMB_	_STATUS_
61	a1	n03	60	1	0	XA103	.	.	1	60	.	64	2	NONKEY ARC BASIC
62	b1	n03	49	1	0	XB103	.	.	0	0	.	65	3	KEY_ARC BASIC
63	c1	n03	60	1	0	XC103	.	.	1	60	.	66	4	NONKEY ARC BASIC
64	d1	n03	60	1	0	XD103	.	.	0	0	.	67	5	NONKEY ARC BASIC
65	e1	n03	42	1	0	XE103	.	.	0	0	-84.000	68	6	LOWERBD NONBASIC
66	f1	n03	60	1	0	XF103	.	.	0	0	.	69	7	NONKEY ARC BASIC
67	g1	n03	59	1	0	XG103	.	.	0	0	.	70	8	NONKEY ARC BASIC
68	h1	n03	60	1	0	XH103	.	.	0	0	-79.000	71	9	LOWERBD NONBASIC
69	i1	n03	51	1	0	XI103	.	.	0	0	.	72	10	NONKEY ARC BASIC
70	j1	n03	45	1	0	XJ103	.	.	0	0	-83.000	73	11	LOWERBD NONBASIC
71	k1	n03	60	1	0	XK103	.	.	0	0	-332.000	74	12	LOWERBD NONBASIC
72	l1	n03	60	1	0	XL103	.	.	1	60	.	75	13	NONKEY ARC BASIC
73	a1	n04	32	1	0	XA104	.	.	1	32	.	76	2	NONKEY ARC BASIC
74	b1	n04	60	1	0	XB104	.	.	0	0	.	77	3	NONKEY ARC BASIC
75	c1	n04	60	1	0	XC104	.	.	1	60	.	78	4	NONKEY ARC BASIC
76	d1	n04	60	1	0	XD104	.	.	0	0	.	79	5	KEY_ARC BASIC
77	e1	n04	60	1	0	XE104	.	.	0	0	.	80	6	NONKEY ARC BASIC
78	f1	n04	90	1	0	XF104	.	.	0	0	.	81	7	NONKEY ARC BASIC
79	g1	n04	90	1	0	XG104	.	.	0	0	.	82	8	NONKEY ARC BASIC
80	h1	n04	90	1	0	XH104	.	.	0	0	.	83	9	NONKEY ARC BASIC
81	i1	n04	88	1	0	XI104	.	.	0	0	.	84	10	NONKEY ARC BASIC
82	j1	n04	60	1	0	XJ104	.	.	0	0	-45.000	85	11	LOWERBD NONBASIC
83	k1	n04	60	1	0	XK104	.	.	0	0	.	86	12	NONKEY ARC BASIC
84	l1	n04	60	1	0	XL104	.	.	1	60	.	87	13	NONKEY ARC BASIC
85	a1	n05	264	1	0	XA105	.	.	1	264	.	88	2	NONKEY ARC BASIC
86	b1	n05	156	1	0	XB105	.	.	0	0	-70.000	89	3	LOWERBD NONBASIC
87	c1	n05	242	1	0	XC105	.	.	1	242	.	90	4	NONKEY ARC BASIC
88	d1	n05	203	1	0	XD105	.	.	0	0	.	91	5	KEY_ARC BASIC
89	e1	n05	162	1	0	XE105	.	.	0	0	.	92	6	NONKEY ARC BASIC
90	f1	n05	178	1	0	XF105	.	.	0	0	.	93	7	NONKEY ARC BASIC
91	g1	n05	162	1	0	XG105	.	.	0	0	.	94	8	NONKEY ARC BASIC
92	h1	n05	169	1	0	XH105	.	.	0	0	.	95	9	NONKEY ARC BASIC
93	i1	n05	150	1	0	XI105	.	.	0	0	.	96	10	NONKEY ARC BASIC
94	j1	n05	150	1	0	XJ105	.	.	0	0	.	97	11	NONKEY ARC BASIC
95	k1	n05	238	1	0	XK105	.	.	0	0	-187.000	98	12	LOWERBD NONBASIC
96	l1	n05	241	1	0	XL105	.	.	1	241	.	99	13	NONKEY ARC BASIC
97	a1	n06	300	1	0	XA106	.	.	1	300	.	100	2	NONKEY ARC BASIC
98	b1	n06	157	1	0	XB106	.	.	0	0	.	101	3	NONKEY ARC BASIC
99	c1	n06	218	1	0	XC106	.	.	1	218	.	102	4	KEY_ARC BASIC
100	d1	n06	185	1	0	XD106	.	.	0	0	.	103	5	NONKEY ARC BASIC
101	e1	n06	155	1	0	XE106	.	.	0	0	.	104	6	NONKEY ARC BASIC
102	f1	n06	171	1	0	XF106	.	.	0	0	.	105	7	NONKEY ARC BASIC
103	g1	n06	160	1	0	XG106	.	.	0	0	-20.000	106	8	LOWERBD NONBASIC
104	h1	n06	165	1	0	XH106	.	.	0	0	-13.000	107	9	LOWERBD NONBASIC
105	i1	n06	149	1	0	XI106	.	.	0	0	-33.000	108	10	LOWERBD NONBASIC
106	j1	n06	152	1	0	XJ106	.	.	0	0	.	109	11	NONKEY ARC BASIC
107	k1	n06	239	1	0	XK106	.	.	0	0	.	110	12	NONKEY ARC BASIC
108	l1	n06	287	1	0	XL106	.	.	1	287	.	111	13	NONKEY ARC BASIC
109	a1	n07	300	1	0	XA107	.	.	1	300	.	112	2	NONKEY ARC BASIC
110	b1	n07	188	1	0	XB107	.	.	0	0	-136.000	113	3	LOWERBD NONBASIC
111	c1	n07	292	1	0	XC107	.	.	1	292	.	114	4	NONKEY ARC BASIC
112	d1	n07	229	1	0	XD107	.	.	0	0	.	115	5	NONKEY ARC BASIC
113	e1	n07	189	1	0	XE107	.	.	0	0	.	116	6	NONKEY ARC BASIC
114	f1	n07	202	1	0	XF107	.	.	0	0	.	117	7	NONKEY ARC BASIC
115	g1	n07	192	1	0	XG107	.	.	0	0	.	118	8	NONKEY ARC BASIC
116	h1	n07	196	1	0	XH107	.	.	0	0	-1.000	119	9	LOWERBD NONBASIC
117	i1	n07	175	1	0	XI107	.	.	0	0	-88.000	120	10	LOWERBD NONBASIC
118	j1	n07	180	1	0	XJ107	.	.	0	0	.	121	11	NONKEY ARC BASIC
119	k1	n07	292	1	0	XK107	.	.	0	0	.	122	12	KEY_ARC BASIC
120	l1	n07	300	1	0	XL107	.	.	1	300	.	123	13	NONKEY ARC BASIC

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121	a1	n08	300	1	0	XA108	.	.	1.00000	300.000	.	124	2	NONKEY ARC BASIC
122	b1	n08	190	1	0	XB108	.	.	0.00000	0.000	-94.000	125	3	LOWERBD NONBASIC
123	c1	n08	272	1	0	XC108	.	.	1.00000	272.000	.	126	4	KEY_ARC BASIC
124	d1	n08	228	1	0	XD108	.	.	0.00000	0.000	-251.000	127	5	LOWERBD NONBASIC
125	e1	n08	193	1	0	XE108	.	.	0.00000	0.000	-6.000	128	6	LOWERBD NONBASIC
126	f1	n08	209	1	0	XF108	.	.	0.00000	0.000	.	129	7	NONKEY ARC BASIC
127	g1	n08	195	1	0	XG108	.	.	0.00000	0.000	.	130	8	NONKEY ARC BASIC
128	h1	n08	202	1	0	XH108	.	.	0.00000	0.000	-18.000	131	9	LOWERBD NONBASIC
129	i1	n08	183	1	0	XI108	.	.	0.00000	0.000	.	132	10	NONKEY ARC BASIC
130	j1	n08	187	1	0	XJ108	.	.	0.00000	0.000	.	133	11	NONKEY ARC BASIC
131	k1	n08	300	1	0	XK108	.	.	0.00000	0.000	.	134	12	NONKEY ARC BASIC
132	l1	n08	300	1	0	XL108	.	.	1.00000	300.000	.	135	13	NONKEY ARC BASIC
133	a1	n09	300	1	0	XA109	.	.	1.00000	300.000	.	136	2	NONKEY ARC BASIC
134	b1	n09	156	1	0	XB109	.	.	0.00000	0.000	.	137	3	NONKEY ARC BASIC
135	c1	n09	213	1	0	XC109	.	.	1.00000	213.000	.	138	4	KEY_ARC BASIC
136	d1	n09	179	1	0	XD109	.	.	0.00000	0.000	.	139	5	NONKEY ARC BASIC
137	e1	n09	158	1	0	XE109	.	.	0.00000	0.000	-307.000	140	6	LOWERBD NONBASIC
138	f1	n09	169	1	0	XF109	.	.	0.00000	0.000	.	141	7	NONKEY ARC BASIC
139	g1	n09	159	1	0	XG109	.	.	0.00000	0.000	.	142	8	NONKEY ARC BASIC
140	h1	n09	159	1	0	XH109	.	.	0.00000	0.000	-21.000	143	9	LOWERBD NONBASIC
141	i1	n09	150	1	0	XI109	.	.	0.00000	0.000	.	144	10	NONKEY ARC BASIC
142	j1	n09	142	1	0	XJ109	.	.	0.00000	0.000	-89.000	145	11	LOWERBD NONBASIC
143	k1	n09	227	1	0	XK109	.	.	0.00000	0.000	.	146	12	NONKEY ARC BASIC
144	l1	n09	261	1	0	XL109	.	.	1.00000	261.000	.	147	13	NONKEY ARC BASIC
145	a1	n10	300	1	0	XA110	.	.	1.00000	300.000	.	148	2	NONKEY ARC BASIC
146	b1	n10	156	1	0	XB110	.	.	0.00000	0.000	.	149	3	NONKEY ARC BASIC
147	c1	n10	217	1	0	XC110	.	.	1.00000	217.000	.	150	4	KEY_ARC BASIC
148	d1	n10	184	1	0	XD110	.	.	0.00000	0.000	-23.000	151	5	LOWERBD NONBASIC
149	e1	n10	158	1	0	XE110	.	.	0.00000	0.000	-99.000	152	6	LOWERBD NONBASIC
150	f1	n10	171	1	0	XF110	.	.	0.00000	0.000	-309.000	153	7	LOWERBD NONBASIC
151	g1	n10	158	1	0	XG110	.	.	0.00000	0.000	-96.000	154	8	LOWERBD NONBASIC
152	h1	n10	163	1	0	XH110	.	.	0.00000	0.000	-90.000	155	9	LOWERBD NONBASIC
153	i1	n10	149	1	0	XI110	.	.	0.00000	0.000	-10.000	156	10	LOWERBD NONBASIC
154	j1	n10	151	1	0	XJ110	.	.	0.00000	0.000	-52.000	157	11	LOWERBD NONBASIC
155	k1	n10	241	1	0	XK110	.	.	0.00000	0.000	.	158	12	NONKEY ARC BASIC
156	l1	n10	288	1	0	XL110	.	.	1.00000	288.000	.	159	13	NONKEY ARC BASIC
157	a1	n11	300	1	0	XA111	.	.	1.00000	300.000	.	160	2	NONKEY ARC BASIC
158	b1	n11	180	1	0	XB111	.	.	0.00000	0.000	.	161	3	NONKEY ARC BASIC
159	c1	n11	295	1	0	XC111	.	.	1.00000	295.000	.	162	4	KEY_ARC BASIC
160	d1	n11	237	1	0	XD111	.	.	0.00000	0.000	.	163	5	NONKEY ARC BASIC
161	e1	n11	180	1	0	XE111	.	.	0.00000	0.000	.	164	6	NONKEY ARC BASIC
162	f1	n11	189	1	0	XF111	.	.	0.00000	0.000	-78.000	165	7	LOWERBD NONBASIC
163	g1	n11	180	1	0	XG111	.	.	0.00000	0.000	.	166	8	NONKEY ARC BASIC
164	h1	n11	180	1	0	XH111	.	.	0.00000	0.000	.	167	9	NONKEY ARC BASIC
165	i1	n11	180	1	0	XI111	.	.	0.00000	0.000	-20.000	168	10	LOWERBD NONBASIC
166	j1	n11	168	1	0	XJ111	.	.	0.00000	0.000	-81.000	169	11	LOWERBD NONBASIC
167	k1	n11	300	1	0	XK111	.	.	0.00000	0.000	.	170	12	NONKEY ARC BASIC
168	l1	n11	300	1	0	XL111	.	.	1.00000	300.000	.	171	13	NONKEY ARC BASIC
169	a1	n12	300	1	0	XA112	.	.	1.00000	300.000	.	172	2	NONKEY ARC BASIC
170	b1	n12	188	1	0	XB112	.	.	0.00000	0.000	-159.000	173	3	LOWERBD NONBASIC
171	c1	n12	289	1	0	XC112	.	.	1.00000	289.000	.	174	4	KEY_ARC BASIC
172	d1	n12	235	1	0	XD112	.	.	0.00000	0.000	-25.000	175	5	LOWERBD NONBASIC
173	e1	n12	198	1	0	XE112	.	.	0.00000	0.000	-79.000	176	6	LOWERBD NONBASIC
174	f1	n12	212	1	0	XF112	.	.	0.00000	0.000	.	177	7	NONKEY ARC BASIC
175	g1	n12	200	1	0	XG112	.	.	0.00000	0.000	-19.000	178	8	LOWERBD NONBASIC
176	h1	n12	208	1	0	XH112	.	.	0.00000	0.000	-405.000	179	9	LOWERBD NONBASIC
177	i1	n12	181	1	0	XI112	.	.	0.00000	0.000	-15.000	180	10	LOWERBD NONBASIC
178	j1	n12	182	1	0	XJ112	.	.	0.00000	0.000	-6.000	181	11	LOWERBD NONBASIC
179	k1	n12	295	1	0	XK112	.	.	0.00000	0.000	.	182	12	NONKEY ARC BASIC
180	l1	n12	300	1	0	XL112	.	.	1.00000	300.000	.	183	13	NONKEY ARC BASIC

OBS	_FROM_	_TO_	_COST_	_CAPAC_	_LO_	_NAME_	_SUPPLY_	_DEMAND_	_FLOW_	_FCOST_	_RCOST_	_ANUMB_	_TNUMB_	_STATUS_
181	a1	n13	300	1	0	XA113	.	.	1	300	.	184	2	NONKEY ARC BASIC
182	b1	n13	191	1	0	XB113	.	.	0	0	-27.00	185	3	LOWERBD NONBASIC
183	c1	n13	291	1	0	XC113	.	.	1	291	.	186	4	KEY_ARC BASIC
184	d1	n13	238	1	0	XD113	.	.	0	0	.	187	5	NONKEY ARC BASIC
185	e1	n13	191	1	0	XE113	.	.	0	0	.	188	6	NONKEY ARC BASIC
186	f1	n13	209	1	0	XF113	.	.	0	0	-71.00	189	7	LOWERBD NONBASIC
187	g1	n13	193	1	0	XG113	.	.	0	0	.	190	8	NONKEY ARC BASIC
188	h1	n13	199	1	0	XH113	.	.	0	0	-29.00	191	9	LOWERBD NONBASIC
189	i1	n13	180	1	0	XI113	.	.	0	0	-130.00	192	10	LOWERBD NONBASIC
190	j1	n13	184	1	0	XJ113	.	.	0	0	.	193	11	NONKEY ARC BASIC
191	k1	n13	293	1	0	XK113	.	.	0	0	.	194	12	NONKEY ARC BASIC
192	l1	n13	299	1	0	XL113	.	.	1	299	.	195	13	NONKEY ARC BASIC
193	a1	n14	300	1	0	XA114	.	.	1	300	.	196	2	NONKEY ARC BASIC
194	b1	n14	180	1	0	XB114	.	.	0	0	.	197	3	NONKEY ARC BASIC
195	c1	n14	293	1	0	XC114	.	.	1	293	.	198	4	KEY_ARC BASIC
196	d1	n14	220	1	0	XD114	.	.	0	0	-44.00	199	5	LOWERBD NONBASIC
197	e1	n14	184	1	0	XE114	.	.	0	0	-7.00	200	6	LOWERBD NONBASIC
198	f1	n14	200	1	0	XF114	.	.	0	0	-93.00	201	7	LOWERBD NONBASIC
199	g1	n14	188	1	0	XG114	.	.	0	0	-5.00	202	8	LOWERBD NONBASIC
200	h1	n14	193	1	0	XH114	.	.	0	0	.	203	9	NONKEY ARC BASIC
201	i1	n14	173	1	0	XI114	.	.	0	0	-32.00	204	10	LOWERBD NONBASIC
202	j1	n14	175	1	0	XJ114	.	.	0	0	-288.00	205	11	LOWERBD NONBASIC
203	k1	n14	298	1	0	XK114	.	.	0	0	.	206	12	NONKEY ARC BASIC
204	l1	n14	300	1	0	XL114	.	.	1	300	.	207	13	NONKEY ARC BASIC
205	a1	n15	300	1	0	XA115	.	.	1	300	295.00	208	2	UPPERBD NONBASIC
206	b1	n15	184	1	0	XB115	.	.	0	0	-109.00	209	3	LOWERBD NONBASIC
207	c1	n15	290	1	0	XC115	.	.	1	290	.	210	4	NONKEY ARC BASIC
208	d1	n15	224	1	0	XD115	.	.	0	0	.	211	5	NONKEY ARC BASIC
209	e1	n15	186	1	0	XE115	.	.	0	0	-5.00	212	6	LOWERBD NONBASIC
210	f1	n15	202	1	0	XF115	.	.	0	0	-56.00	213	7	LOWERBD NONBASIC
211	g1	n15	188	1	0	XG115	.	.	0	0	-98.00	214	8	LOWERBD NONBASIC
212	h1	n15	192	1	0	XH115	.	.	0	0	-45.00	215	9	LOWERBD NONBASIC
213	i1	n15	174	1	0	XI115	.	.	0	0	-138.00	216	10	LOWERBD NONBASIC
214	j1	n15	176	1	0	XJ115	.	.	0	0	.	217	11	NONKEY ARC BASIC
215	k1	n15	294	1	0	XK115	.	.	0	0	.	218	12	NONKEY ARC BASIC
216	l1	n15	298	1	0	XL115	.	.	1	298	.	219	13	NONKEY ARC BASIC
217	a1	n16	300	1	0	XA116	.	.	1	300	.	220	2	NONKEY ARC BASIC
218	b1	n16	180	1	0	XB116	.	.	0	0	-87.00	221	3	LOWERBD NONBASIC
219	c1	n16	292	1	0	XC116	.	.	1	292	.	222	4	KEY_ARC BASIC
220	d1	n16	219	1	0	XD116	.	.	0	0	.	223	5	NONKEY ARC BASIC
221	e1	n16	183	1	0	XE116	.	.	0	0	-84.00	224	6	LOWERBD NONBASIC
222	f1	n16	199	1	0	XF116	.	.	0	0	-45.00	225	7	LOWERBD NONBASIC
223	g1	n16	186	1	0	XG116	.	.	0	0	-23.00	226	8	LOWERBD NONBASIC
224	h1	n16	190	1	0	XH116	.	.	0	0	-57.00	227	9	LOWERBD NONBASIC
225	i1	n16	171	1	0	XI116	.	.	0	0	.	228	10	NONKEY ARC BASIC
226	j1	n16	173	1	0	XJ116	.	.	0	0	-103.00	229	11	LOWERBD NONBASIC
227	k1	n16	294	1	0	XK116	.	.	0	0	-99999852.00	230	12	LOWERBD NONBASIC
228	l1	n16	299	1	0	XL116	.	.	1	299	.	231	13	NONKEY ARC BASIC
229	a2	n17	0	1	0	XA217	.	.	1	0	.	232	15	NONKEY ARC BASIC
230	b2	n17	146	1	0	XB217	.	.	0	0	.	233	16	KEY_ARC BASIC
231	c2	n17	73	1	0	XC217	.	.	1	73	544.00	234	17	UPPERBD NONBASIC
232	d2	n17	112	1	0	XD217	.	.	0	0	.	235	18	NONKEY ARC BASIC
233	e2	n17	144	1	0	XE217	.	.	0	0	-2.00	236	19	LOWERBD NONBASIC

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234	f2	n17	129	1	0	XF217	.	.	0	0	.	237	20	NONKEY ARC BASIC
235	g2	n17	140	1	0	XG217	.	.	0	0	-7.000	238	21	LOWERBD NONBASIC
236	h2	n17	135	1	0	XH217	.	.	0	0	.	239	22	NONKEY ARC BASIC
237	i2	n17	154	1	0	XI217	.	.	0	0	.	240	23	NONKEY ARC BASIC
238	j2	n17	152	1	0	XJ217	.	.	0	0	.	241	24	NONKEY ARC BASIC
239	k2	n17	38	1	0	XK217	.	.	0	0	.	242	25	NONKEY ARC BASIC
240	l2	n17	0	1	0	XL217	.	.	1	0	.	243	26	NONKEY ARC BASIC
241	a2	n18	0	1	0	XA218	.	.	1	0	.	244	15	NONKEY ARC BASIC
242	b2	n18	168	1	0	XB218	.	.	0	0	-20.000	245	16	LOWERBD NONBASIC
243	c2	n18	122	1	0	XC218	.	.	1	122	.	246	17	NONKEY ARC BASIC
244	d2	n18	145	1	0	XD218	.	.	0	0	-13.000	247	18	LOWERBD NONBASIC
245	e2	n18	169	1	0	XE218	.	.	0	0	.	248	19	NONKEY ARC BASIC
246	f2	n18	156	1	0	XF218	.	.	0	0	-2.000	249	20	LOWERBD NONBASIC
247	g2	n18	164	1	0	XG218	.	.	0	0	.	250	21	KEY_ARC BASIC
248	h2	n18	160	1	0	XH218	.	.	0	0	.	251	22	NONKEY ARC BASIC
249	i2	n18	176	1	0	XI218	.	.	0	0	-1.000	252	23	LOWERBD NONBASIC
250	j2	n18	175	1	0	XJ218	.	.	0	0	.	253	24	NONKEY ARC BASIC
251	k2	n18	107	1	0	XK218	.	.	0	0	.	254	25	NONKEY ARC BASIC
252	l2	n18	91	1	0	XL218	.	.	1	91	50.000	255	26	UPPERBD NONBASIC
253	a2	n19	0	1	0	XA219	.	.	1	0	.	256	15	NONKEY ARC BASIC
254	b2	n19	182	1	0	XB219	.	.	0	0	-88.000	257	16	LOWERBD NONBASIC
255	c2	n19	151	1	0	XC219	.	.	1	151	.	258	17	KEY_ARC BASIC
256	d2	n19	166	1	0	XD219	.	.	0	0	.	259	18	NONKEY ARC BASIC
257	e2	n19	180	1	0	XE219	.	.	0	0	.	260	19	KEY_ARC BASIC
258	f2	n19	174	1	0	XF219	.	.	0	0	-87.000	261	20	LOWERBD NONBASIC
259	g2	n19	180	1	0	XG219	.	.	0	0	-132.000	262	21	LOWERBD NONBASIC
260	h2	n19	177	1	0	XH219	.	.	0	0	.	263	22	NONKEY ARC BASIC
261	i2	n19	187	1	0	XI219	.	.	0	0	-76.000	264	23	LOWERBD NONBASIC
262	j2	n19	185	1	0	XJ219	.	.	0	0	.	265	24	NONKEY ARC BASIC
263	k2	n19	144	1	0	XK219	.	.	0	0	.	266	25	NONKEY ARC BASIC
264	l2	n19	135	1	0	XL219	.	.	1	135	.	267	26	NONKEY ARC BASIC
265	a2	n20	60	1	0	XA220	.	.	1	60	.	268	15	NONKEY ARC BASIC
266	b2	n20	60	1	0	XB220	.	.	0	0	.	269	16	NONKEY ARC BASIC
267	c2	n20	60	1	0	XC220	.	.	1	60	.	270	17	NONKEY ARC BASIC
268	d2	n20	60	1	0	XD220	.	.	0	0	-51.000	271	18	LOWERBD NONBASIC
269	e2	n20	60	1	0	XE220	.	.	0	0	.	272	19	NONKEY ARC BASIC
270	f2	n20	60	1	0	XF220	.	.	0	0	.	273	20	NONKEY ARC BASIC
271	g2	n20	60	1	0	XG220	.	.	0	0	.	274	21	NONKEY ARC BASIC
272	h2	n20	60	1	0	XH220	.	.	0	0	.	275	22	NONKEY ARC BASIC
273	i2	n20	60	1	0	XI220	.	.	0	0	.	276	23	KEY_ARC BASIC
274	j2	n20	60	1	0	XJ220	.	.	0	0	.	277	24	NONKEY ARC BASIC
275	k2	n20	60	1	0	XK220	.	.	0	0	.	278	25	NONKEY ARC BASIC
276	l2	n20	60	1	0	XL220	.	.	1	60	.	279	26	NONKEY ARC BASIC
277	a2	n21	36	1	0	XA221	.	.	1	36	.	280	15	NONKEY ARC BASIC
278	b2	n21	187	1	0	XB221	.	.	0	0	.	281	16	NONKEY ARC BASIC
279	c2	n21	207	1	0	XC221	.	.	1	207	.	282	17	NONKEY ARC BASIC
280	d2	n21	212	1	0	XD221	.	.	0	0	.	283	18	KEY_ARC BASIC
281	e2	n21	201	1	0	XE221	.	.	0	0	-90.000	284	19	LOWERBD NONBASIC
282	f2	n21	215	1	0	XF221	.	.	0	0	-23.000	285	20	LOWERBD NONBASIC
283	g2	n21	219	1	0	XG221	.	.	0	0	-23.000	286	21	LOWERBD NONBASIC
284	h2	n21	217	1	0	XH221	.	.	0	0	.	287	22	NONKEY ARC BASIC
285	i2	n21	164	1	0	XI221	.	.	0	0	-151.000	288	23	LOWERBD NONBASIC
286	j2	n21	170	1	0	XJ221	.	.	0	0	-86.000	289	24	LOWERBD NONBASIC
287	k2	n21	203	1	0	XK221	.	.	0	0	.	290	25	NONKEY ARC BASIC
288	l2	n21	200	1	0	XL221	.	.	1	200	.	291	26	NONKEY ARC BASIC
289	a2	n22	61	1	0	XA222	.	.	1	61	.	292	15	NONKEY ARC BASIC
290	b2	n22	224	1	0	XB222	.	.	0	0	-261.000	293	16	LOWERBD NONBASIC
291	c2	n22	197	1	0	XC222	.	.	1	197	.	294	17	NONKEY ARC BASIC
292	d2	n22	212	1	0	XD222	.	.	0	0	.	295	18	NONKEY ARC BASIC
293	e2	n22	214	1	0	XE222	.	.	0	0	.	296	19	NONKEY ARC BASIC

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294	f2	n22	212	1	0	XF222	.	.	0	0	.	297	20	NONKEY ARC BASIC
295	g2	n22	211	1	0	XG222	.	.	0	0	.	298	21	NONKEY ARC BASIC
296	h2	n22	212	1	0	XH222	.	.	0	0	.	299	22	NONKEY ARC BASIC
297	i2	n22	213	1	0	XI222	.	.	0	0	.	300	23	KEY_ARC BASIC
298	j2	n22	214	1	0	XJ222	.	.	0	0	.	301	24	NONKEY ARC BASIC
299	k2	n22	196	1	0	XK222	.	.	0	0	.	302	25	NONKEY ARC BASIC
300	l2	n22	190	1	0	XL222	.	.	1	190	.	303	26	NONKEY ARC BASIC
301	a2	n23	300	1	0	XA223	.	.	1	300	.	304	15	NONKEY ARC BASIC
302	b2	n23	240	1	0	XB223	.	.	0	0	.	305	16	NONKEY ARC BASIC
303	c2	n23	251	1	0	XC223	.	.	1	251	.	306	17	KEY_ARC BASIC
304	d2	n23	246	1	0	XD223	.	.	0	0	.	307	18	NONKEY ARC BASIC
305	e2	n23	238	1	0	XE223	.	.	0	0	-49.00	308	19	LOWERBD NONBASIC
306	f2	n23	242	1	0	XF223	.	.	0	0	.	309	20	NONKEY ARC BASIC
307	g2	n23	240	1	0	XG223	.	.	0	0	-84.00	310	21	LOWERBD NONBASIC
308	h2	n23	241	1	0	XH223	.	.	0	0	-41.00	311	22	LOWERBD NONBASIC
309	i2	n23	237	1	0	XI223	.	.	0	0	.	312	23	NONKEY ARC BASIC
310	j2	n23	237	1	0	XJ223	.	.	0	0	-23.00	313	24	LOWERBD NONBASIC
311	k2	n23	256	1	0	XK223	.	.	0	0	-99999918.00	314	25	LOWERBD NONBASIC
312	l2	n23	260	1	0	XL223	.	.	1	260	.	315	26	NONKEY ARC BASIC
313	a2	n24	300	1	0	XA224	.	.	1	300	.	316	15	NONKEY ARC BASIC
314	b2	n24	239	1	0	XB224	.	.	0	0	.	317	16	NONKEY ARC BASIC
315	c2	n24	252	1	0	XC224	.	.	1	252	.	318	17	KEY_ARC BASIC
316	d2	n24	246	1	0	XD224	.	.	0	0	.	319	18	NONKEY ARC BASIC
317	e2	n24	240	1	0	XE224	.	.	0	0	-8.00	320	19	LOWERBD NONBASIC
318	f2	n24	243	1	0	XF224	.	.	0	0	-59.00	321	20	LOWERBD NONBASIC
319	g2	n24	240	1	0	XG224	.	.	0	0	.	322	21	NONKEY ARC BASIC
320	h2	n24	241	1	0	XH224	.	.	0	0	-20.00	323	22	LOWERBD NONBASIC
321	i2	n24	238	1	0	XI224	.	.	0	0	-114.00	324	23	LOWERBD NONBASIC
322	j2	n24	239	1	0	XJ224	.	.	0	0	.	325	24	NONKEY ARC BASIC
323	k2	n24	255	1	0	XK224	.	.	0	0	-85.00	326	25	LOWERBD NONBASIC
324	l2	n24	261	1	0	XL224	.	.	1	261	22.00	327	26	UPPERBD NONBASIC
325	a2	n25	300	1	0	XA225	.	.	1	300	.	328	15	NONKEY ARC BASIC
326	b2	n25	214	1	0	XB225	.	.	0	0	-68.00	329	16	LOWERBD NONBASIC
327	c2	n25	290	1	0	XC225	.	.	1	290	.	330	17	KEY_ARC BASIC
328	d2	n25	277	1	0	XD225	.	.	0	0	.	331	18	NONKEY ARC BASIC
329	e2	n25	219	1	0	XE225	.	.	0	0	-0.00	332	19	LOWERBD NONBASIC
330	f2	n25	250	1	0	XF225	.	.	0	0	-2.00	333	20	LOWERBD NONBASIC
331	g2	n25	224	1	0	XG225	.	.	0	0	-50.00	334	21	LOWERBD NONBASIC
332	h2	n25	232	1	0	XH225	.	.	0	0	.	335	22	NONKEY ARC BASIC
333	i2	n25	200	1	0	XI225	.	.	0	0	-123.00	336	23	LOWERBD NONBASIC
334	j2	n25	205	1	0	XJ225	.	.	0	0	-5.00	337	24	LOWERBD NONBASIC
335	k2	n25	300	1	0	XK225	.	.	0	0	.	338	25	NONKEY ARC BASIC
336	l2	n25	300	1	0	XL225	.	.	1	300	90.00	339	26	UPPERBD NONBASIC
337	a2	n26	300	1	0	XA226	.	.	1	300	.	340	15	NONKEY ARC BASIC
338	b2	n26	163	1	0	XB226	.	.	0	0	.	341	16	NONKEY ARC BASIC
339	c2	n26	215	1	0	XC226	.	.	1	215	.	342	17	KEY_ARC BASIC
340	d2	n26	185	1	0	XD226	.	.	0	0	.	343	18	NONKEY ARC BASIC
341	e2	n26	163	1	0	XE226	.	.	0	0	-1.00	344	19	LOWERBD NONBASIC
342	f2	n26	173	1	0	XF226	.	.	0	0	.	345	20	NONKEY ARC BASIC
343	g2	n26	166	1	0	XG226	.	.	0	0	.	346	21	NONKEY ARC BASIC
344	h2	n26	169	1	0	XH226	.	.	0	0	.	347	22	NONKEY ARC BASIC
345	i2	n26	153	1	0	XI226	.	.	0	0	-115.00	348	23	LOWERBD NONBASIC
346	j2	n26	155	1	0	XJ226	.	.	0	0	.	349	24	NONKEY ARC BASIC

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347	k2	n26	234	1	0	XK226	.	.	0	0	.	350	25	NONKEY ARC BASIC
348	l2	n26	254	1	0	XL226	.	.	1	254	99.000	351	26	UPPERBD NONBASIC
349	a2	n27	300	1	0	XA227	.	.	1	300	322.000	352	15	UPPERBD NONBASIC
350	b2	n27	157	1	0	XB227	.	.	0	0	-111.000	353	16	LOWERBD NONBASIC
351	c2	n27	215	1	0	XC227	.	.	1	215	.	354	17	KEY_ARC BASIC
352	d2	n27	180	1	0	XD227	.	.	0	0	.	355	18	NONKEY ARC BASIC
353	e2	n27	155	1	0	XE227	.	.	0	0	-109.000	356	19	LOWERBD NONBASIC
354	f2	n27	166	1	0	XF227	.	.	0	0	.	357	20	NONKEY ARC BASIC
355	g2	n27	154	1	0	XG227	.	.	0	0	-352.000	358	21	LOWERBD NONBASIC
356	h2	n27	158	1	0	XH227	.	.	0	0	-108.000	359	22	LOWERBD NONBASIC
357	i2	n27	144	1	0	XI227	.	.	0	0	-119.000	360	23	LOWERBD NONBASIC
358	j2	n27	150	1	0	XJ227	.	.	0	0	.	361	24	NONKEY ARC BASIC
359	k2	n27	232	1	0	XK227	.	.	0	0	.	362	25	NONKEY ARC BASIC
360	l2	n27	265	1	0	XL227	.	.	1	265	115.000	363	26	UPPERBD NONBASIC
361	a2	n28	300	1	0	XA228	.	.	1	300	.	364	15	NONKEY ARC BASIC
362	b2	n28	245	1	0	XB228	.	.	0	0	.	365	16	NONKEY ARC BASIC
363	c2	n28	296	1	0	XC228	.	.	1	296	.	366	17	KEY_ARC BASIC
364	d2	n28	288	1	0	XD228	.	.	0	0	.	367	18	NONKEY ARC BASIC
365	e2	n28	251	1	0	XE228	.	.	0	0	-58.000	368	19	LOWERBD NONBASIC
366	f2	n28	280	1	0	XF228	.	.	0	0	-76.000	369	20	LOWERBD NONBASIC
367	g2	n28	255	1	0	XG228	.	.	0	0	-109.000	370	21	LOWERBD NONBASIC
368	h2	n28	267	1	0	XH228	.	.	0	0	.	371	22	NONKEY ARC BASIC
369	i2	n28	219	1	0	XI228	.	.	0	0	-194.000	372	23	LOWERBD NONBASIC
370	j2	n28	224	1	0	XJ228	.	.	0	0	-76.000	373	24	LOWERBD NONBASIC
371	k2	n28	300	1	0	XK228	.	.	0	0	.	374	25	NONKEY ARC BASIC
372	l2	n28	300	1	0	XL228	.	.	1	300	.	375	26	NONKEY ARC BASIC
373	a2	n29	300	1	0	XA229	.	.	1	300	.	376	15	NONKEY ARC BASIC
374	b2	n29	168	1	0	XB229	.	.	0	0	.	377	16	NONKEY ARC BASIC
375	c2	n29	243	1	0	XC229	.	.	1	243	.	378	17	KEY_ARC BASIC
376	d2	n29	202	1	0	XD229	.	.	0	0	.	379	18	NONKEY ARC BASIC
377	e2	n29	173	1	0	XE229	.	.	0	0	-58.000	380	19	LOWERBD NONBASIC
378	f2	n29	186	1	0	XF229	.	.	0	0	.	381	20	NONKEY ARC BASIC
379	g2	n29	174	1	0	XG229	.	.	0	0	-112.000	382	21	LOWERBD NONBASIC
380	h2	n29	177	1	0	XH229	.	.	0	0	-67.000	383	22	LOWERBD NONBASIC
381	i2	n29	162	1	0	XI229	.	.	0	0	-173.000	384	23	LOWERBD NONBASIC
382	j2	n29	162	1	0	XJ229	.	.	0	0	-60.000	385	24	LOWERBD NONBASIC
383	k2	n29	295	1	0	XK229	.	.	0	0	.	386	25	NONKEY ARC BASIC
384	l2	n29	299	1	0	XL229	.	.	1	299	77.000	387	26	UPPERBD NONBASIC
385	a2	n30	300	1	0	XA230	.	.	1	300	.	388	15	NONKEY ARC BASIC
386	b2	n30	168	1	0	XB230	.	.	0	0	.	389	16	NONKEY ARC BASIC
387	c2	n30	244	1	0	XC230	.	.	1	244	.	390	17	KEY_ARC BASIC
388	d2	n30	202	1	0	XD230	.	.	0	0	.	391	18	NONKEY ARC BASIC
389	e2	n30	172	1	0	XE230	.	.	0	0	-21.000	392	19	LOWERBD NONBASIC
390	f2	n30	185	1	0	XF230	.	.	0	0	.	393	20	NONKEY ARC BASIC
391	g2	n30	172	1	0	XG230	.	.	0	0	-76.000	394	21	LOWERBD NONBASIC
392	h2	n30	178	1	0	XH230	.	.	0	0	-28.000	395	22	LOWERBD NONBASIC
393	i2	n30	161	1	0	XI230	.	.	0	0	-136.000	396	23	LOWERBD NONBASIC
394	j2	n30	162	1	0	XJ230	.	.	0	0	-22.000	397	24	LOWERBD NONBASIC
395	k2	n30	295	1	0	XK230	.	.	0	0	.	398	25	NONKEY ARC BASIC
396	l2	n30	298	1	0	XL230	.	.	1	298	114.000	399	26	UPPERBD NONBASIC
397	a2	n31	300	1	0	XA231	.	.	1	300	.	400	15	NONKEY ARC BASIC
398	b2	n31	191	1	0	XB231	.	.	0	0	.	401	16	NONKEY ARC BASIC
399	c2	n31	289	1	0	XC231	.	.	1	289	.	402	17	KEY_ARC BASIC
400	d2	n31	237	1	0	XD231	.	.	0	0	.	403	18	NONKEY ARC BASIC
401	e2	n31	196	1	0	XE231	.	.	0	0	-40.000	404	19	LOWERBD NONBASIC
402	f2	n31	214	1	0	XF231	.	.	0	0	.	405	20	NONKEY ARC BASIC
403	g2	n31	198	1	0	XG231	.	.	0	0	.	406	21	NONKEY ARC BASIC
404	h2	n31	205	1	0	XH231	.	.	0	0	.	407	22	NONKEY ARC BASIC
405	i2	n31	180	1	0	XI231	.	.	0	0	.	408	23	NONKEY ARC BASIC
406	j2	n31	182	1	0	XJ231	.	.	0	0	-45.000	409	24	LOWERBD NONBASIC

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407	k2	n31	293	1	0	XK231	.	.	0	0	-328.00	410	25	LOWERBD NONBASIC
408	l2	n31	298	1	0	XL231	.	.	1	298	71.00	411	26	UPPERBD NONBASIC
409	a2	n32	300	1	0	XA232	.	.	1	300	.	412	15	NONKEY ARC BASIC
410	b2	n32	181	1	0	XB232	.	.	0	0	.	413	16	NONKEY ARC BASIC
411	c2	n32	292	1	0	XC232	.	.	1	292	.	414	17	KEY_ARC BASIC
412	d2	n32	221	1	0	XD232	.	.	0	0	-2.00	415	18	LOWERBD NONBASIC
413	e2	n32	185	1	0	XE232	.	.	0	0	.	416	19	NONKEY ARC BASIC
414	f2	n32	200	1	0	XF232	.	.	0	0	.	417	20	NONKEY ARC BASIC
415	g2	n32	186	1	0	XG232	.	.	0	0	-54.00	418	21	LOWERBD NONBASIC
416	h2	n32	192	1	0	XH232	.	.	0	0	-6.00	419	22	LOWERBD NONBASIC
417	i2	n32	174	1	0	XI232	.	.	0	0	-115.00	420	23	LOWERBD NONBASIC
418	j2	n32	176	1	0	XJ232	.	.	0	0	.	421	24	NONKEY ARC BASIC
419	k2	n32	295	1	0	XK232	.	.	0	0	.	422	25	NONKEY ARC BASIC
420	l2	n32	298	1	0	XL232	.	.	1	298	122.00	423	26	UPPERBD NONBASIC
421	a3	n33	0	1	0	XA333	.	.	1	0	.	424	28	NONKEY ARC BASIC
422	b3	n33	139	1	0	XB333	.	.	0	0	.	425	29	NONKEY ARC BASIC
423	c3	n33	47	1	0	XC333	.	.	1	47	.	426	30	NONKEY ARC BASIC
424	d3	n33	100	1	0	XD333	.	.	0	0	.	427	31	NONKEY ARC BASIC
425	e3	n33	134	1	0	XE333	.	.	0	0	.	428	32	KEY_ARC BASIC
426	f3	n33	119	1	0	XF333	.	.	0	0	.	429	33	NONKEY ARC BASIC
427	g3	n33	132	1	0	XG333	.	.	0	0	.	430	34	NONKEY ARC BASIC
428	h3	n33	127	1	0	XH333	.	.	0	0	.	431	35	NONKEY ARC BASIC
429	i3	n33	148	1	0	XI333	.	.	0	0	.	432	36	NONKEY ARC BASIC
430	j3	n33	144	1	0	XJ333	.	.	0	0	.	433	37	KEY_ARC BASIC
431	k3	n33	0	1	0	XK333	.	.	0	0	-99999775.00	434	38	LOWERBD NONBASIC
432	l3	n33	0	1	0	XL333	.	.	1	0	.	435	39	NONKEY ARC BASIC
433	a3	n34	64	1	0	XA334	.	.	1	64	.	436	28	NONKEY ARC BASIC
434	b3	n34	64	1	0	XB334	.	.	0	0	.	437	29	NONKEY ARC BASIC
435	c3	n34	64	1	0	XC334	.	.	1	64	.	438	30	NONKEY ARC BASIC
436	d3	n34	64	1	0	XD334	.	.	0	0	.	439	31	KEY_ARC BASIC
437	e3	n34	64	1	0	XE334	.	.	0	0	.	440	32	NONKEY ARC BASIC
438	f3	n34	64	1	0	XF334	.	.	0	0	.	441	33	NONKEY ARC BASIC
439	g3	n34	64	1	0	XG334	.	.	0	0	-6.00	442	34	LOWERBD NONBASIC
440	h3	n34	64	1	0	XH334	.	.	0	0	.	443	35	NONKEY ARC BASIC
441	i3	n34	60	1	0	XI334	.	.	0	0	.	444	36	NONKEY ARC BASIC
442	j3	n34	56	1	0	XJ334	.	.	0	0	.	445	37	KEY_ARC BASIC
443	k3	n34	64	1	0	XK334	.	.	0	0	-99999775.00	446	38	LOWERBD NONBASIC
444	l3	n34	64	1	0	XL334	.	.	1	64	.	447	39	NONKEY ARC BASIC
445	a3	n35	62	1	0	XA335	.	.	1	62	.	448	28	NONKEY ARC BASIC
446	b3	n35	57	1	0	XB335	.	.	0	0	.	449	29	NONKEY ARC BASIC
447	c3	n35	59	1	0	XC335	.	.	1	59	.	450	30	NONKEY ARC BASIC
448	d3	n35	67	1	0	XD335	.	.	0	0	-86.00	451	31	LOWERBD NONBASIC
449	e3	n35	61	1	0	XE335	.	.	0	0	.	452	32	NONKEY ARC BASIC
450	f3	n35	61	1	0	XF335	.	.	0	0	.	453	33	NONKEY ARC BASIC
451	g3	n35	62	1	0	XG335	.	.	0	0	.	454	34	NONKEY ARC BASIC
452	h3	n35	62	1	0	XH335	.	.	0	0	.	455	35	KEY_ARC BASIC
453	i3	n35	56	1	0	XI335	.	.	0	0	.	456	36	NONKEY ARC BASIC
454	j3	n35	56	1	0	XJ335	.	.	0	0	.	457	37	NONKEY ARC BASIC
455	k3	n35	62	1	0	XK335	.	.	0	0	-99999768.00	458	38	LOWERBD NONBASIC
456	l3	n35	55	1	0	XL335	.	.	1	55	.	459	39	NONKEY ARC BASIC
457	a3	n36	60	1	0	XA336	.	.	1	60	.	460	28	NONKEY ARC BASIC
458	b3	n36	60	1	0	XB336	.	.	0	0	-57.00	461	29	LOWERBD NONBASIC
459	c3	n36	60	1	0	XC336	.	.	1	60	.	462	30	NONKEY ARC BASIC

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460	d3	n36	90	1	0	XD336	.	.	0	0	.	463	31	NONKEY ARC BASIC
461	e3	n36	60	1	0	XE336	.	.	0	0	-45.00	464	32	LOWERBD NONBASIC
462	f3	n36	90	1	0	XF336	.	.	0	0	-51.00	465	33	LOWERBD NONBASIC
463	g3	n36	90	1	0	XG336	.	.	0	0	.	466	34	NONKEY ARC BASIC
464	h3	n36	90	1	0	XH336	.	.	0	0	.	467	35	NONKEY ARC BASIC
465	i3	n36	90	1	0	XI336	.	.	0	0	.	468	36	KEY_ARC BASIC
466	j3	n36	60	1	0	XJ336	.	.	0	0	.	469	37	NONKEY ARC BASIC
467	k3	n36	30	1	0	XK336	.	.	0	0	-100000044.00	470	38	LOWERBD NONBASIC
468	l3	n36	60	1	0	XL336	.	.	1	60	72.00	471	39	UPPERBD NONBASIC
469	a3	n37	300	1	0	XA337	.	.	1	300	.	472	28	NONKEY ARC BASIC
470	b3	n37	243	1	0	XB337	.	.	0	0	.	473	29	NONKEY ARC BASIC
471	c3	n37	244	1	0	XC337	.	.	1	244	.	474	30	NONKEY ARC BASIC
472	d3	n37	244	1	0	XD337	.	.	0	0	.	475	31	KEY_ARC BASIC
473	e3	n37	222	1	0	XE337	.	.	0	0	.	476	32	NONKEY ARC BASIC
474	f3	n37	244	1	0	XF337	.	.	0	0	.	477	33	NONKEY ARC BASIC
475	g3	n37	244	1	0	XG337	.	.	0	0	.	478	34	NONKEY ARC BASIC
476	h3	n37	214	1	0	XH337	.	.	0	0	-48.00	479	35	LOWERBD NONBASIC
477	i3	n37	183	1	0	XI337	.	.	0	0	.	480	36	NONKEY ARC BASIC
478	j3	n37	243	1	0	XJ337	.	.	0	0	-2.00	481	37	LOWERBD NONBASIC
479	k3	n37	244	1	0	XK337	.	.	0	0	-99999775.00	482	38	LOWERBD NONBASIC
480	l3	n37	244	1	0	XL337	.	.	1	244	.	483	39	NONKEY ARC BASIC
481	a3	n38	214	1	0	XA338	.	.	1	214	.	484	28	NONKEY ARC BASIC
482	b3	n38	148	1	0	XB338	.	.	0	0	.	485	29	NONKEY ARC BASIC
483	c3	n38	164	1	0	XC338	.	.	1	164	.	486	30	KEY_ARC BASIC
484	d3	n38	155	1	0	XD338	.	.	0	0	.	487	31	NONKEY ARC BASIC
485	e3	n38	149	1	0	XE338	.	.	0	0	-22.00	488	32	LOWERBD NONBASIC
486	f3	n38	152	1	0	XF338	.	.	0	0	-32.00	489	33	LOWERBD NONBASIC
487	g3	n38	149	1	0	XG338	.	.	0	0	.	490	34	NONKEY ARC BASIC
488	h3	n38	150	1	0	XH338	.	.	0	0	.	491	35	NONKEY ARC BASIC
489	i3	n38	145	1	0	XI338	.	.	0	0	.	492	36	NONKEY ARC BASIC
490	j3	n38	148	1	0	XJ338	.	.	0	0	-26.00	493	37	LOWERBD NONBASIC
491	k3	n38	169	1	0	XK338	.	.	0	0	-99999935.00	494	38	LOWERBD NONBASIC
492	l3	n38	173	1	0	XL338	.	.	1	173	.	495	39	NONKEY ARC BASIC
493	a3	n39	300	1	0	XA339	.	.	1	300	.	496	28	NONKEY ARC BASIC
494	b3	n39	149	1	0	XB339	.	.	0	0	.	497	29	NONKEY ARC BASIC
495	c3	n39	214	1	0	XC339	.	.	1	214	.	498	30	NONKEY ARC BASIC
496	d3	n39	180	1	0	XD339	.	.	0	0	.	499	31	NONKEY ARC BASIC
497	e3	n39	154	1	0	XE339	.	.	0	0	-29.00	500	32	LOWERBD NONBASIC
498	f3	n39	167	1	0	XF339	.	.	0	0	-36.00	501	33	LOWERBD NONBASIC
499	g3	n39	158	1	0	XG339	.	.	0	0	.	502	34	NONKEY ARC BASIC
500	h3	n39	159	1	0	XH339	.	.	0	0	-9.00	503	35	LOWERBD NONBASIC
501	i3	n39	147	1	0	XI339	.	.	0	0	.	504	36	NONKEY ARC BASIC
502	j3	n39	149	1	0	XJ339	.	.	0	0	-58.00	505	37	LOWERBD NONBASIC
503	k3	n39	232	1	0	XK339	.	.	0	0	.	506	38	KEY_ARC BASIC
504	l3	n39	250	1	0	XL339	.	.	1	250	44.00	507	39	UPPERBD NONBASIC
505	a3	n40	300	1	0	XA340	.	.	1	300	.	508	28	NONKEY ARC BASIC
506	b3	n40	191	1	0	XB340	.	.	0	0	.	509	29	NONKEY ARC BASIC
507	c3	n40	300	1	0	XC340	.	.	1	300	.	510	30	NONKEY ARC BASIC
508	d3	n40	230	1	0	XD340	.	.	0	0	.	511	31	NONKEY ARC BASIC
509	e3	n40	180	1	0	XE340	.	.	0	0	-95.00	512	32	LOWERBD NONBASIC
510	f3	n40	215	1	0	XF340	.	.	0	0	.	513	33	KEY_ARC BASIC
511	g3	n40	193	1	0	XG340	.	.	0	0	-86.00	514	34	LOWERBD NONBASIC
512	h3	n40	182	1	0	XH340	.	.	0	0	-78.00	515	35	LOWERBD NONBASIC

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513	i3	n40	179	1	0	XI340	.	.	0	0	.	516	36	NONKEY ARC BASIC
514	j3	n40	180	1	0	XJ340	.	.	0	0	-119.00	517	37	LOWERBD NONBASIC
515	k3	n40	290	1	0	XK340	.	.	0	0	-99999783.00	518	38	LOWERBD NONBASIC
516	l3	n40	298	1	0	XL340	.	.	1	298	.	519	39	NONKEY ARC BASIC
517	a3	n41	300	1	0	XA341	.	.	1	300	.	520	28	NONKEY ARC BASIC
518	b3	n41	186	1	0	XB341	.	.	0	0	.	521	29	NONKEY ARC BASIC
519	c3	n41	284	1	0	XC341	.	.	1	284	.	522	30	KEY_ARC BASIC
520	d3	n41	234	1	0	XD341	.	.	0	0	.	523	31	NONKEY ARC BASIC
521	e3	n41	199	1	0	XE341	.	.	0	0	.	524	32	NONKEY ARC BASIC
522	f3	n41	211	1	0	XF341	.	.	0	0	.	525	33	NONKEY ARC BASIC
523	g3	n41	203	1	0	XG341	.	.	0	0	.	526	34	NONKEY ARC BASIC
524	h3	n41	212	1	0	XH341	.	.	0	0	.	527	35	NONKEY ARC BASIC
525	i3	n41	178	1	0	XI341	.	.	0	0	.	528	36	NONKEY ARC BASIC
526	j3	n41	179	1	0	XJ341	.	.	0	0	-4.00	529	37	LOWERBD NONBASIC
527	k3	n41	296	1	0	XK341	.	.	0	0	-99999800.00	530	38	LOWERBD NONBASIC
528	l3	n41	298	1	0	XL341	.	.	1	298	116.00	531	39	UPPERBD NONBASIC
529	a3	n42	300	1	0	XA342	.	.	1	300	.	532	28	NONKEY ARC BASIC
530	b3	n42	144	1	0	XB342	.	.	0	0	-97.00	533	29	LOWERBD NONBASIC
531	c3	n42	192	1	0	XC342	.	.	1	192	.	534	30	KEY_ARC BASIC
532	d3	n42	168	1	0	XD342	.	.	0	0	.	535	31	NONKEY ARC BASIC
533	e3	n42	142	1	0	XE342	.	.	0	0	-63.00	536	32	LOWERBD NONBASIC
534	f3	n42	153	1	0	XF342	.	.	0	0	.	537	33	NONKEY ARC BASIC
535	g3	n42	144	1	0	XG342	.	.	0	0	-4.00	538	34	LOWERBD NONBASIC
536	h3	n42	150	1	0	XH342	.	.	0	0	.	539	35	NONKEY ARC BASIC
537	i3	n42	133	1	0	XI342	.	.	0	0	.	540	36	NONKEY ARC BASIC
538	j3	n42	133	1	0	XJ342	.	.	0	0	-96.00	541	37	LOWERBD NONBASIC
539	k3	n42	204	1	0	XK342	.	.	0	0	-99999880.00	542	38	LOWERBD NONBASIC
540	l3	n42	228	1	0	XL342	.	.	1	228	.	543	39	NONKEY ARC BASIC
541	a3	n43	300	1	0	XA343	.	.	1	300	.	544	28	NONKEY ARC BASIC
542	b3	n43	158	1	0	XB343	.	.	0	0	.	545	29	NONKEY ARC BASIC
543	c3	n43	222	1	0	XC343	.	.	1	222	.	546	30	KEY_ARC BASIC
544	d3	n43	189	1	0	XD343	.	.	0	0	.	547	31	NONKEY ARC BASIC
545	e3	n43	162	1	0	XE343	.	.	0	0	.	548	32	NONKEY ARC BASIC
546	f3	n43	173	1	0	XF343	.	.	0	0	.	549	33	NONKEY ARC BASIC
547	g3	n43	164	1	0	XG343	.	.	0	0	.	550	34	NONKEY ARC BASIC
548	h3	n43	168	1	0	XH343	.	.	0	0	.	551	35	NONKEY ARC BASIC
549	i3	n43	155	1	0	XI343	.	.	0	0	.	552	36	NONKEY ARC BASIC
550	j3	n43	153	1	0	XJ343	.	.	0	0	-54.00	553	37	LOWERBD NONBASIC
551	k3	n43	251	1	0	XK343	.	.	0	0	-99999849.00	554	38	LOWERBD NONBASIC
552	l3	n43	300	1	0	XL343	.	.	1	300	94.00	555	39	UPPERBD NONBASIC
553	a3	n44	300	1	0	XA344	.	.	1	300	.	556	28	NONKEY ARC BASIC
554	b3	n44	182	1	0	XB344	.	.	0	0	.	557	29	NONKEY ARC BASIC
555	c3	n44	290	1	0	XC344	.	.	1	290	.	558	30	KEY_ARC BASIC
556	d3	n44	226	1	0	XD344	.	.	0	0	.	559	31	NONKEY ARC BASIC
557	e3	n44	188	1	0	XE344	.	.	0	0	.	560	32	NONKEY ARC BASIC
558	f3	n44	206	1	0	XF344	.	.	0	0	.	561	33	NONKEY ARC BASIC
559	g3	n44	191	1	0	XG344	.	.	0	0	.	562	34	NONKEY ARC BASIC
560	h3	n44	196	1	0	XH344	.	.	0	0	.	563	35	NONKEY ARC BASIC
561	i3	n44	173	1	0	XI344	.	.	0	0	.	564	36	NONKEY ARC BASIC
562	j3	n44	176	1	0	XJ344	.	.	0	0	-122.00	565	37	LOWERBD NONBASIC
563	k3	n44	294	1	0	XK344	.	.	0	0	-99999884.00	566	38	LOWERBD NONBASIC
564	l3	n44	297	1	0	XL344	.	.	1	297	.	567	39	NONKEY ARC BASIC
565	a3	n45	300	1	0	XA345	.	.	1	300	262.00	568	28	UPPERBD NONBASIC

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566	b3	n45	182	1	0	XB345	.	.	0	0	-98.00	569	29	LOWERBD NONBASIC
567	c3	n45	288	1	0	XC345	.	.	1	288	.	570	30	KEY_ARC BASIC
568	d3	n45	226	1	0	XD345	.	.	0	0	.	571	31	NONKEY ARC BASIC
569	e3	n45	186	1	0	XE345	.	.	0	0	-58.00	572	32	LOWERBD NONBASIC
570	f3	n45	200	1	0	XF345	.	.	0	0	.	573	33	NONKEY ARC BASIC
571	g3	n45	187	1	0	XG345	.	.	0	0	.	574	34	NONKEY ARC BASIC
572	h3	n45	194	1	0	XH345	.	.	0	0	.	575	35	NONKEY ARC BASIC
573	i3	n45	173	1	0	XI345	.	.	0	0	-90.00	576	36	LOWERBD NONBASIC
574	j3	n45	176	1	0	XJ345	.	.	0	0	-92.00	577	37	LOWERBD NONBASIC
575	k3	n45	292	1	0	XK345	.	.	0	0	-99999797.00	578	38	LOWERBD NONBASIC
576	l3	n45	297	1	0	XL345	.	.	1	297	30.00	579	39	UPPERBD NONBASIC
577	a3	n46	300	1	0	XA346	.	.	1	300	.	580	28	NONKEY ARC BASIC
578	b3	n46	164	1	0	XB346	.	.	0	0	-148.00	581	29	LOWERBD NONBASIC
579	c3	n46	236	1	0	XC346	.	.	1	236	.	582	30	KEY_ARC BASIC
580	d3	n46	194	1	0	XD346	.	.	0	0	.	583	31	NONKEY ARC BASIC
581	e3	n46	167	1	0	XE346	.	.	0	0	-109.00	584	32	LOWERBD NONBASIC
582	f3	n46	182	1	0	XF346	.	.	0	0	.	585	33	NONKEY ARC BASIC
583	g3	n46	168	1	0	XG346	.	.	0	0	-51.00	586	34	LOWERBD NONBASIC
584	h3	n46	174	1	0	XH346	.	.	0	0	-87.00	587	35	LOWERBD NONBASIC
585	i3	n46	158	1	0	XI346	.	.	0	0	.	588	36	NONKEY ARC BASIC
586	j3	n46	160	1	0	XJ346	.	.	0	0	-140.00	589	37	LOWERBD NONBASIC
587	k3	n46	271	1	0	XK346	.	.	0	0	-99999803.00	590	38	LOWERBD NONBASIC
588	l3	n46	299	1	0	XL346	.	.	1	299	.	591	39	NONKEY ARC BASIC
589	a3	n47	300	1	0	XA347	.	.	1	300	.	592	28	NONKEY ARC BASIC
590	b3	n47	149	1	0	XB347	.	.	0	0	.	593	29	NONKEY ARC BASIC
591	c3	n47	199	1	0	XC347	.	.	1	199	.	594	30	KEY_ARC BASIC
592	d3	n47	172	1	0	XD347	.	.	0	0	.	595	31	NONKEY ARC BASIC
593	e3	n47	148	1	0	XE347	.	.	0	0	-58.00	596	32	LOWERBD NONBASIC
594	f3	n47	161	1	0	XF347	.	.	0	0	.	597	33	NONKEY ARC BASIC
595	g3	n47	149	1	0	XG347	.	.	0	0	.	598	34	NONKEY ARC BASIC
596	h3	n47	154	1	0	XH347	.	.	0	0	-37.00	599	35	LOWERBD NONBASIC
597	i3	n47	141	1	0	XI347	.	.	0	0	.	600	36	NONKEY ARC BASIC
598	j3	n47	144	1	0	XJ347	.	.	0	0	-86.00	601	37	LOWERBD NONBASIC
599	k3	n47	215	1	0	XK347	.	.	0	0	-99999789.00	602	38	LOWERBD NONBASIC
600	l3	n47	230	1	0	XL347	.	.	1	230	1.00	603	39	UPPERBD NONBASIC
601	a3	n48	165	1	0	XA348	.	.	1	165	186.00	604	28	UPPERBD NONBASIC
602	b3	n48	159	1	0	XB348	.	.	0	0	.	605	29	NONKEY ARC BASIC
603	c3	n48	165	1	0	XC348	.	.	1	165	.	606	30	NONKEY ARC BASIC
604	d3	n48	165	1	0	XD348	.	.	0	0	.	607	31	NONKEY ARC BASIC
605	e3	n48	155	1	0	XE348	.	.	0	0	.	608	32	NONKEY ARC BASIC
606	f3	n48	163	1	0	XF348	.	.	0	0	.	609	33	NONKEY ARC BASIC
607	g3	n48	158	1	0	XG348	.	.	0	0	.	610	34	NONKEY ARC BASIC
608	h3	n48	162	1	0	XH348	.	.	0	0	.	611	35	NONKEY ARC BASIC
609	i3	n48	147	1	0	XI348	.	.	0	0	.	612	36	NONKEY ARC BASIC
610	j3	n48	155	1	0	XJ348	.	.	0	0	.	613	37	NONKEY ARC BASIC
611	k3	n48	165	1	0	XK348	.	.	0	0	.	614	38	KEY_ARC BASIC
612	l3	n48	165	1	0	XL348	.	.	1	165	.	615	39	NONKEY ARC BASIC
613	t	s1	0	99999999	0	XTS1	.	.	48	0	.	1	88	KEY_ARC BASIC
614	t	s2	0	99999999	0	XTS2	.	.	48	0	.	14	88	KEY_ARC BASIC
615	t	s3	0	99999999	0	XTS3	.	.	48	0	.	27	88	KEY_ARC BASIC
616	n01	t	0	3	0	X01T	.	D	3	0	257.00	616	40	UPPERBD NONBASIC
617	n02	t	0	3	0	X02T	.	D	3	0	.	617	41	NONKEY ARC BASIC
618	n03	t	0	3	0	X03T	.	D	3	0	.	618	42	NONKEY ARC BASIC

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619	n04	t	0	3	0	X04T	.	D	3	0	.	619	43	NONKEY ARC BASIC
620	n05	t	0	3	0	X05T	.	D	3	0	27.000	620	44	UPPERBD NONBASIC
621	n06	t	0	3	0	X06T	.	D	3	0	.	621	45	NONKEY ARC BASIC
622	n07	t	0	3	0	X07T	.	D	3	0	4.000	622	46	UPPERBD NONBASIC
623	n08	t	0	3	0	X08T	.	D	3	0	.	623	47	NONKEY ARC BASIC
624	n09	t	0	3	0	X09T	.	D	3	0	55.000	624	48	UPPERBD NONBASIC
625	n10	t	0	3	0	X10T	.	D	3	0	.	625	49	NONKEY ARC BASIC
626	n11	t	0	3	0	X11T	.	D	3	0	73.000	626	50	UPPERBD NONBASIC
627	n12	t	0	3	0	X12T	.	D	3	0	.	627	51	NONKEY ARC BASIC
628	n13	t	0	3	0	X13T	.	D	3	0	.	628	52	NONKEY ARC BASIC
629	n14	t	0	3	0	X14T	.	D	3	0	.	629	53	NONKEY ARC BASIC
630	n15	t	0	3	0	X15T	.	D	3	0	.	630	54	KEY_ARC BASIC
631	n16	t	0	3	0	X16T	.	D	3	0	89.000	631	55	UPPERBD NONBASIC
632	n17	t	0	3	0	X17T	.	D	3	0	.	632	56	NONKEY ARC BASIC
633	n18	t	0	3	0	X18T	.	D	3	0	41.000	633	57	UPPERBD NONBASIC
634	n19	t	0	3	0	X19T	.	D	3	0	135.000	634	58	UPPERBD NONBASIC
635	n20	t	0	3	0	X20T	.	D	3	0	60.000	635	59	UPPERBD NONBASIC
636	n21	t	0	3	0	X21T	.	D	3	0	200.000	636	60	UPPERBD NONBASIC
637	n22	t	0	3	0	X22T	.	D	3	0	190.000	637	61	UPPERBD NONBASIC
638	n23	t	0	3	0	X23T	.	D	3	0	260.000	638	62	UPPERBD NONBASIC
639	n24	t	0	3	0	X24T	.	D	3	0	239.000	639	63	UPPERBD NONBASIC
640	n25	t	0	3	0	X25T	.	D	3	0	210.000	640	64	UPPERBD NONBASIC
641	n26	t	0	3	0	X26T	.	D	3	0	155.000	641	65	UPPERBD NONBASIC
642	n27	t	0	3	0	X27T	.	D	3	0	150.000	642	66	UPPERBD NONBASIC
643	n28	t	0	3	0	X28T	.	D	3	0	300.000	643	67	UPPERBD NONBASIC
644	n29	t	0	3	0	X29T	.	D	3	0	222.000	644	68	UPPERBD NONBASIC
645	n30	t	0	3	0	X30T	.	D	3	0	184.000	645	69	UPPERBD NONBASIC
646	n31	t	0	3	0	X31T	.	D	3	0	227.000	646	70	UPPERBD NONBASIC
647	n32	t	0	3	0	X32T	.	D	3	0	176.000	647	71	UPPERBD NONBASIC
648	n33	t	0	3	0	X33T	.	D	3	0	201.125	648	72	UPPERBD NONBASIC
649	n34	t	0	3	0	X34T	.	D	3	0	265.125	649	73	UPPERBD NONBASIC
650	n35	t	0	3	0	X35T	.	D	3	0	256.125	650	74	UPPERBD NONBASIC
651	n36	t	0	3	0	X36T	.	D	3	0	189.125	651	75	UPPERBD NONBASIC
652	n37	t	0	3	0	X37T	.	D	3	0	445.125	652	76	UPPERBD NONBASIC
653	n38	t	0	3	0	X38T	.	D	3	0	374.125	653	77	UPPERBD NONBASIC
654	n39	t	0	3	0	X39T	.	D	3	0	407.125	654	78	UPPERBD NONBASIC
655	n40	t	0	3	0	X40T	.	D	3	0	499.125	655	79	UPPERBD NONBASIC
656	n41	t	0	3	0	X41T	.	D	3	0	383.125	656	80	UPPERBD NONBASIC
657	n42	t	0	3	0	X42T	.	D	3	0	429.125	657	81	UPPERBD NONBASIC
658	n43	t	0	3	0	X43T	.	D	3	0	407.125	658	82	UPPERBD NONBASIC
659	n44	t	0	3	0	X44T	.	D	3	0	498.125	659	83	UPPERBD NONBASIC
660	n45	t	0	3	0	X45T	.	D	3	0	468.125	660	84	UPPERBD NONBASIC
661	n46	t	0	3	0	X46T	.	D	3	0	500.125	661	85	UPPERBD NONBASIC
662	n47	t	0	3	0	X47T	.	D	3	0	430.125	662	86	UPPERBD NONBASIC
663	n48	t	0	3	0	X48T	.	D	3	0	366.125	663	87	UPPERBD NONBASIC
664			0	99999999	0	XS1A2	.	.	16	0	.	0	.	NONKEY BASIC
										=======				
										30845				

Appendix X. *Linear Programming Formulation of Network With Gains*

Maximize

$$\begin{aligned}
&20x_{1,10} + 22x_{1,11} + 24x_{1,12} + 21x_{1,13}\\
&+23x_{2,10} + 19x_{2,11} + 28x_{2,12} + 22x_{2,13}\\
&+27x_{3,10} + 23x_{3,11} + 21x_{3,12} + 25x_{3,13}\\
&+21x_{4,14} + 27x_{4,15} + 25x_{4,16} + 21x_{4,17}\\
&+21x_{5,14} + 23x_{5,15} + 23x_{5,16} + 23x_{5,17}\\
&+19x_{6,14} + 28x_{6,15} + 26x_{6,16} + 26x_{6,17}\\
&+28x_{7,18} + 24x_{7,19} + 23x_{7,20} + 22x_{7,21}\\
&+24x_{8,18} + 23x_{8,19} + 23x_{8,20} + 19x_{8,21}\\
&+26x_{9,18} + 22x_{9,19} + 22x_{9,20} + 19x_{9,21}
\end{aligned}$$

All other arcs have a weight of zero.

Subject to:

$$\begin{aligned}
&x_{s,1} + x_{s,2} + x_{s,3} - p = 0\\
&x_{1,10} + x_{1,11} + x_{1,12} + x_{1,13} + x_{1,4} - 5x_{s,1} = 0\\
&x_{2,10} + x_{2,11} + x_{2,12} + x_{2,13} + x_{2,5} - 5x_{s,2} = 0\\
&x_{3,10} + x_{3,11} + x_{3,12} + x_{3,13} + x_{3,6} - 5x_{s,3} = 0\\
&x_{4,14} + x_{4,15} + x_{4,16} + x_{4,17} + x_{4,7} - 5x_{1,4} = 0\\
&x_{5,14} + x_{5,15} + x_{5,16} + x_{5,17} + x_{5,8} - 5x_{2,5} = 0\\
&x_{6,14} + x_{6,15} + x_{6,16} + x_{6,17} + x_{6,9} - 5x_{3,6} = 0\\
&x_{7,18} + x_{7,19} + x_{7,20} + x_{7,21} - 4x_{4,7} = 0\\
&x_{8,18} + x_{8,19} + x_{8,20} + x_{8,21} - 4x_{5,8} = 0\\
&x_{9,18} + x_{9,19} + x_{9,20} + x_{9,21} - 4x_{6,9} = 0\\
&x_{1,10} + x_{2,10} + x_{3,10} - x_{10,t} = 0\\
&x_{1,11} + x_{2,11} + x_{3,11} - x_{11,t} = 0\\
&x_{1,12} + x_{2,12} + x_{3,12} - x_{12,t} = 0\\
&x_{1,13} + x_{2,13} + x_{3,13} - x_{13,t} = 0\\
&x_{4,14} + x_{5,14} + x_{6,14} - x_{14,t} = 0\\
&x_{4,15} + x_{5,15} + x_{6,15} - x_{15,t} = 0\\
&x_{4,16} + x_{5,16} + x_{6,16} - x_{16,t} = 0\\
&x_{4,17} + x_{5,17} + x_{6,17} - x_{17,t} = 0\\
&x_{7,18} + x_{8,18} + x_{9,18} - x_{18,t} = 0\\
&x_{7,19} + x_{8,19} + x_{9,19} - x_{19,t} = 0\\
&x_{7,20} + x_{8,20} + x_{9,20} - x_{20,t} = 0\\
&x_{7,21} + x_{8,21} + x_{9,21} - x_{21,t} = 0\\
&9p - x_{10,t} - x_{11,t} - x_{12,t} - x_{13,t} - x_{14,t} - x_{15,t} - x_{16,t} - x_{17,t} - x_{18,t} - x_{19,t} - x_{20,t} - x_{21,t} = 0\\
&p = 1
\end{aligned}$$

Source–Connector Flows

$$\begin{aligned}
x_{s,1} &\le 1\\
x_{s,2} &\le 1\\
x_{s,3} &\le 1
\end{aligned}$$

Sink-Connector Flows

$$x_{10,t} - p = 0$$
$$x_{11,t} - p = 0$$
$$x_{12,t} - p = 0$$
$$x_{13,t} - p = 0$$
$$x_{14,t} - p = 0$$
$$x_{15,t} - p = 0$$
$$x_{16,t} - p = 0$$
$$x_{17,t} - p = 0$$
$$x_{18,t} - p = 0$$
$$x_{19,t} - p = 0$$
$$x_{20,t} - p = 0$$
$$x_{21,t} - p = 0$$

Equi-Distribution of Flow

$$x_{1,10} - x_{s,1} = 0$$
$$x_{1,11} - x_{s,1} = 0$$
$$x_{1,12} - x_{s,1} = 0$$
$$x_{1,13} - x_{s,1} = 0$$
$$x_{1,4} - x_{s,1} = 0$$
$$x_{2,10} - x_{s,2} = 0$$
$$x_{2,11} - x_{s,2} = 0$$
$$x_{2,12} - x_{s,2} = 0$$
$$x_{2,13} - x_{s,2} = 0$$
$$x_{2,5} - x_{s,2} = 0$$
$$x_{3,10} - x_{s,3} = 0$$
$$x_{3,11} - x_{s,3} = 0$$
$$x_{3,12} - x_{s,3} = 0$$
$$x_{3,13} - x_{s,3} = 0$$
$$x_{3,6} - x_{s,3} = 0$$
$$x_{4,14} - x_{s,4} = 0$$
$$x_{4,15} - x_{s,4} = 0$$
$$x_{4,16} - x_{s,4} = 0$$
$$x_{4,17} - x_{s,4} = 0$$
$$x_{4,7} - x_{s,4} = 0$$
$$x_{5,14} - x_{s,5} = 0$$
$$x_{5,15} - x_{s,5} = 0$$
$$x_{5,16} - x_{s,5} = 0$$
$$x_{5,17} - x_{s,5} = 0$$
$$x_{5,8} - x_{s,5} = 0$$
$$x_{6,14} - x_{s,6} = 0$$
$$x_{6,15} - x_{s,6} = 0$$
$$x_{6,16} - x_{s,6} = 0$$
$$x_{6,17} - x_{s,6} = 0$$
$$x_{6,9} - x_{s,6} = 0$$
$$x_{7,18} - x_{s,7} = 0$$
$$x_{7,19} - x_{s,7} = 0$$
$$x_{7,20} - x_{s,7} = 0$$
$$x_{7,21} - x_{s,7} = 0$$
$$x_{8,18} - x_{s,8} = 0$$
$$x_{8,19} - x_{s,8} = 0$$
$$x_{8,20} - x_{s,8} = 0$$
$$x_{8,21} - x_{s,8} = 0$$
$$x_{9,18} - x_{s,9} = 0$$
$$x_{9,19} - x_{s,9} = 0$$
$$x_{9,20} - x_{s,9} = 0$$
$$x_{9,21} - x_{s,9} = 0$$

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Vita

Captain William George Schick was born on December 12, 1956. He graduated at the top of his class from Central High School in Moose Jaw, Saskatchewan in June of 1975. He attended Royal Roads Military College (RRMC) from August 1975 to May 1977 and the Royal Military College of Canada (RMC) from August 1977 to May 1979. Upon graduation with a Bachelor of Engineering in Chemical Engineering, he was presented with his commission. After a year of pilot training Capt Schick recieved his wings on helicopters in October 1980. His first tour was on CH-135's as a Base Rescue pilot at CFB Cold Lake, Alberta. In July of 1981, he married the former Judy Ann Arnold of Richmond, Indiana. Captain Schick was promoted to his present rank May 1, 1982. In August of 1984 he was transferred to 424 Transport and Rescue Squadron as a Search and Rescue pilot. Capt Schick entered the United States Naval Test Pilot School in January 1986 and upon graduation in December 1986 as a Qualified Test Pilot was transferred to the Aerospace Engineering Test Establishment (AETE) at CFB Cold Lake, Alberta. After four and one-half years of flight testing, Capt Schick entered the School of Engineering, Air Force Institute of Technology, Wright-Patterson AFB, Ohio.

Permanent address: Moose Jaw, Saskatchewan,
Canada

OMB No. 0704-0188

December 1992 | Master's Thesis

5. FUNDING NUMBERS

LOCATING AN IMAGING RADAR IN CANADA FOR IDENTIFYING SPACEBORNE OBJECTS

William G. Schick, Captain, CF

Air Force Institute of Technology, WPAFB OH 45433-6583

8. PERFORMING ORGANIZATION REPORT NUMBER

AFIT/GSO/ENS/ENY/92D-13

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Defence Headquarters
Directorate of Air Operations and Training
Ottawa, Canada
K1A 0K2

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

This research presents a study of the maximal coverage p-median facility location problem as applied to the location of an imaging radar in Canada for imaging spaceborne objects. The classical mathematical formulation of the maximal coverage p-median problem is converted into network-flow with side constraint formulations that are developed using a scaled down version of the imaging radar location problem.

Two types of network-flow with side constraint formulations are developed: a network using side constraints that simulates the gains in a generalized network; and a network resembling a multi-commodity flow problem that uses side constraints to force flow along identical arcs. These small formulations are expanded to encompass a case study using 12 candidate radar sites, and 48 satellites divided into three states. SAS/OR PROC NETFLOW was used to solve the network-flow with side constraint formulations.

The case study shows the potential for both formulations, although the simulated gains formulation encountered singular matrix computational difficulties as a result of the very organized nature of its side constraint matrix. The multi-commodity flow formulation, when combined with equi-distribution of flow constraints, provided solutions for various values of p, the number of facilities to be selected.

14. SUBJECT TERMS

Facility Location, Imaging Radar, Mathematical Programming, Networks With Side Constraints

15. NUMBER OF PAGES

240

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL